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LAPLANTE

H. H. Atwood.

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ELEMENTS

OF

CHEMISTRY,

FOR

COMMON AND HIGH SCHOOLS.

Clark

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PREFACE.

Descriptive chemistry can be studied with greatest benefit in early youth. The experiments which impart a knowledge of the simple qualities of bodies are a source of exquisite delight to the young; they are but a passing pleasure to the adult. The minds of young people easily assimilate such knowledge, because it is so perfectly adapted to their wants; the minds of those more advanced in years and attainments retain it only by laborious effort, because they have reached a stage of development to which it does not essentially minister. I have long believed, and each year's experience is making the conviction deeper, that a clear and permament knowledge of the physical and chemical properties of elements and compounds, usually studied in mineral chemistry, can be more readily attained, and with better mental discipline, by boys and girls under the age of fifteen years, than by the senior class in college.

But for this early culture I would not touch the technicalities, the mathematics, nor the logic in which the science so abounds, and which render it one of the most powerful educational forces in the higher courses of study. Nature has a simple and delightful story for the young; let her tell it in her own simple and dignified way. She is, indeed, able to puzzle the wisest philosopher, and does so whenever he attempts to unveil the rare secrets of her ag-

tivities ; but she has a "Youth's Department," containing the history of water, of air, of the rocks and the soil—in a word, of things common and useful—in which is an abundance of material by which she entertains, instructs, strengthens and polishes the minds of the young.

Such views as these have prompted the preparation of this little chemistry for beginners.

CHEMISTRY.

PHYSICAL AND CHEMICAL CHANGES.

Describe the apparatus shown in the picture.—A glass tube several inches long is bent at one end, and there passes through the cork of a small bottle. The other end of the tube is slipped into an india rubber tube, which may be put between the lips. A little colored water is in the glass tube, about half-way between the bottle and the india rubber.

Fig. 1.

Describe an experiment with this apparatus.—The neck of the bottle is grasped in the left hand, the rubber tube in the right. The lips are applied to the mouth-piece of the rubber and then the breath is very gently blown into the tube. The colored water will then run rapidly toward the bottle, but let the lips be opened, and it will as quickly spring back to its place.

Describe another experiment with it.—Let the breath be gently drawn out of the tube; and the colored water will hasten further away from the bottle, but if the lips are opened, it will speedily leap back again.

Describe another experiment with the same apparatus.—Let the breath be gently but rapidly blown into the tube and withdrawn several times in succession, and the colored water will be seen to perform a lively dance back and forth in the tube.

Explain these experiments.—The bottle is full of air, so is the tube down to the colored water. This air cannot get out, nor can any more get in. Then, when the breath is pushed into the tube, the air is crowded forward into the bottle—it is *compressed.* But when the breath is drawn out of the tube, the air in the bottle grows larger and pushes the water along before it—the air is *expanded.*

When the breath is first blown into the tube and then quickly withdrawn, the compression and the expansion take place in succession, and the dance of the water is produced.

What change is made in the air by these experiments?—The motion of the water toward the bottle and back again shows that the air in the bottle is made smaller at one time and larger at another. This change in its size is the only change which can be seen.

Does any other change occur?—There is one other change taking place in the air. We cannot see it occur, but we know that it does. It is a change in density, and this is the way we know that it takes place :

When the water in the tube moves toward the bottle, it must push the air along in front of it. The air cannot get out of the bottle, and so we are certain that there is more air in the bottle than there was before, and since there is more air in the same space, it must be more dense.

What should be noticed about these changes?—these changes are not *changes in the nature* of the air. The

air while being compressed or expanded—while being made more dense or more rare—is precisely the same substance as when no such changes occur.

Mention another change of this kind.—In the melting of ice the solid becomes a liquid, but it remains exactly the same substance as before. There is no change *in the nature* of the water.

What are such changes called?—Changes like these are called *physical changes.* Hence *physical changes are those during which the nature of the substances remains the same.*

Describe the experiment shown in Fig. 2.—A piece of card-board is put over the top of an ale glass. A teaspoonful of sugar and another of potassic chlorate are powdered and mixed, and then laid upon the card-board. Three or four drops of strong sulphuric acid are allowed to fall from the end of a glass tube upon this mixture. Almost upon the instant when the acid touches the mixture, violet-colored tongues of flame leap up from it with a hissing sound, accompanied with large volumes of white vapor passing off into the air. When the sound has ceased, and the colored flames have died out, only a coal-black mass is left upon the card-board.

Fig. 2.

What changes have occurred in this experiment?—The white mixture of sugar and potassic chlorate, with the drops of oily-looking acid, have been changed into vapors, which have gone into the air, and a black coaly mass, which is left behind. Not a particle of either of the substances used can be found remaining. These changes are changes *in the nature* of the substances.

Describe the experiment with sulphur and potassic chlorate.—Take a piece of potassic chlorate about as

large as a grain of wheat, and about an equal quantity of sulphur. Put them together in a mortar and rub the mixture with the pestle vigorously. A loud explosion or a series of lesser explosions is produced. If the rubbing be continued, the explosions will also continue until the mixture has wholly disappeared from the mortar.

What change may be noticed in this experiment?—The yellow solid sulphur and the white solid potassic chlorate have both been changed into gases of very different character. The two substances used have become something else. The change is a change *in the nature* of the substances.

What are such changes called?—Changes like those seen in these experiments—changes in which some bodies are converted into others—are called chemical changes.

Chemical changes are those in which the nature of the substances are altered.

Mention familiar cases of chemical change.—When wood burns it ceases to be wood ; it is changed to smoke and vapor and ash. When coal burns in the grate or the furnace it is coal no longer ; gases, ash and cinder are all that remains. When gunpowder explodes it ceases to be gunpowder ; it becomes a mass of gas and vapor, which quickly disappears in the air.

These changes are all chemical changes, because they are changes in the nature of substances.

What do we learn by studying these chemical changes?—By the study of chemical changes we may learn about the different kinds of matter to be found in bodies. Some of these kinds of matter are so very different from the things which can be seen around us, that one cannot fail to be surprised, and perhaps astonished, when he first sees them or is made acquainted with their curious properties.

In what science do we study chemical changes? —Now it is the science of chemistry which teaches us about these chemical changes and their results.

Chemistry is the science which treats of the composition and properties of bodies of matter, and explains the chemical changes which bodies may show.

THE CHEMISTRY OF WATER.

Who was Von Helmont?—More than two hundred years ago there lived a man by the name of Von Helmont. We have all heard of Galileo; Von Helmont lived at the same time. He was one of the noted men of science of that age. He took pleasure in trying all sorts of curious experiments, and by them he learned a great many things that people had never known before, nor even dreamed of. But he did not always read his experiments right, and on this account he sometimes took from them curious notions, which people have since then learned to be false.

What were some of his curious notions?—He thought, for example, that there must be some way to turn copper or any other cheap metal into gold or silver, and he thought that if he could only find it out, he could fill the world with precious metals, and then everybody would be rich at once.

Another curious notion of Von Helmont was that water could be changed into stone.

Why did he think this?—He thought that he had actually done this himself a great many times. He talked about it in this way:

Whenever I boil water it slowly disappears, and no matter how pure it may seem, it always leaves some solid matter at the bottom of the vessel in which it is heated. Now where can this solid matter have come from? Surely it is the water changed into stone by the fire.

The wisest men made great mistakes two hundred years ago. About some things they knew less than children may know now if they will try to learn. But let us hasten to ask :

How did people learn that Von Helmont was wrong? —About one hundred years ago there lived a Frenchman by the name of Lavoisier. He knew that people believed just

Fig. 3.

LAVOISIER.

as Von Helmont had taught them a century before, but after all, he could not quite believe that water could be boiled into stone, and he determined to find out if possible. He went to work in this way :

He took a kind of boiler, made of glass, and in such a shape that while one part was being heated another would remain cold. He weighed out some clear water, put it into the boiler, shut it up tight, and then set it boiling. The

steam from the boiling water would go over into the cold part of the boiler, change back to water, and then run down into the heated part to be boiled over again. No steam could get out and nothing could get in.

And now, said Lavoisier, if any of this water is changed into stone there will not be as much left as I put in, and by and by I will weigh it and find out. He kept that water boiling all the time during one hundred days and nights! Surely the fire had the best possible chance to change the water into stone if it could, but after all this time he found exactly as much water in the boiler as he had put into it at first, so that not a particle had been changed into stone or anything else.

Since that experiment everybody has learned to think it just as impossible to change water into stone as it is to change stone into bread. But we are not to suppose on this account that water cannot be changed into anything else; a change even more wonderful than that which Von Helmont erroneously believed in can be wrought in this limpid liquid.

How can water be changed into something else?— We have here, (Fig. 4,) at the left hand, a vessel containing water. Through the bottom two wires reach up into the fluid, and are long enough to reach the other way over to a galvanic battery at the right. Now the moment that the ends of these wires are joined to the poles of the battery, *little bubbles of colorless gas* begin to rise, in multitudes, from the other ends in the vessel of water.

The water will gradually be used up, too slowly to be noticed in a short experiment, but still fast enough, so that after a long time it may be known, and instead of the water, which seems to be lost, there is the colorless gas which bubbles away from the wires. The water is being changed into gas.

How can we catch this gas?—Nothing is more simple. The picture shows how it is done. Two tall tubes of

Fig. 4.

glass are first filled with water, and then inverted, one over each wire in the vessel. The bubbles of gas have then no escape; they rise up into the tubes; the water is pushed out, and finally the tubes are filled with gas. But if they were full of air they would look just as they now do; has the water been changed into atmospheric air?

How can we tell what the tubes contain?—We must examine the gases in the tubes and learn whether they are atmospheric air by finding out whether they will *act* as well as *look* like it. This we can do by means of a lighted match or taper. See how easily it may be done.

Let the gas in the tube over the wire which is fastened to the zinc of the battery—the left-hand tube in the picture—be examined, first. We grasp it in the fingers of the left hand, and at the same time close its mouth tightly with the thumb.

We lift it from the water and turn its closed mouth upward. We take a lighted match in the right hand, and take the thumb from the mouth of the tube at the same moment that the flame is brought directly over it. Listen! See! A slight explosion and a feeble flame! The gas exploded and then burned away. Air will not do these things; this gas cannot be air. Let us name it at once. The chemist calls it HYDROGEN.

Is the other the same?—We shall find it to be very different. Lift the tube from the water just as the other was lifted. Uncover it and quickly bring the flame of the match over it as before. No explosion—no flame; this is not hydrogen gas.

But extinguish the flame of the match, a little red coal being left upon its end. Plunge this gloomy spark down into the tube. See! It bursts quickly into a flame far more brilliant than it had before it was extinguished. This was no accident, for if we take the burning match out and again extinguish all but a little spark of its fire, and then again plunge it, perhaps a little deeper, into the tube, it is relighted and burns as brilliantly as before. The gas in this tube has been able to do what air cannot. It is not air. The chemist calls it OXYGEN. And now have we not answered the question—

Into what can water be changed?—By the action of the electricity the water was converted into the two gases, hydrogen and oxygen.

Von Helmont thought that water could be changed into stone, but that was a fiction; is not this new truth more strange than the old fiction?

But we have two kinds of matter new to us, now introduced to our attention. Let us try to become better acquainted with them.

HYDROGEN.

The small quantity of hydrogen which we are able to get by means of electricity will not be enough to teach us all we may like to learn about this curious gas. The first question to answer is this :

How can we obtain hydrogen for experiments?— It is one of the simplest things the chemist has to do. Look at the picture, (Fig. 5.) At the right hand we see a glass bottle with two necks, both corked. Before the corks were

Fig. 5.

put into the necks, some pieces of zinc were placed in the bottle. Some water mixed with sulphuric acid is poured through the tall funnel-tube upon the zinc. Very soon the liquid begins to boil, not because it is boiling hot, but because bubbles of hydrogen gas are set free so very fast. This gas very soon drives all the air out of the bottle, through the bent tube, into the water contained in a cistern, and then itself

comes over from the bottle in a steady stream. To catch it, a tall glass jar is filled with water and turned bottom upward, with its open mouth over the end of the tube from which the gas is bubbling. Very speedily this jar will be filled ; it may then be taken away and another put in its place.

But how do we know that the jars are filled with hydrogen?—We can see nothing at all in the jar if the gas it contains is pure. But let us lift it out of the cistern and touch the flame of a taper or a match to its mouth. Quick as thought a sharp explosion is heard and a dull flame is seen. The gas that explodes and burns we know to be hydrogen.

Having another jar of hydrogen, we are able at once to find out :

What are some of its physical properties?—We can see the jar which holds it, but the gas is too colorless and transparent to be visible. It is also without taste and without odor.

There is another physical property which the gas, as it stands in the jar, cannot show us. Let us make an experiment to find out something about its weight.

Is hydrogen lighter or heavier than air?—Let us take two small glass vessels, and fill one with hydrogen, the other with air. Then suppose we bring them together, as we may see them shown in Fig. 6, so that the one containing hydrogen shall be above the other. Next turn them quickly over, to bring the air vessel to the top. Will the hydrogen stay at the bottom? Not so, for if we remove the lower jar and then touch the mouth of the upper one with a lighted match, a sharp explosion tells us that the hydrogen is there. Hydrogen has risen through the air to the top just as oil will rise through water to its surface. It is lighter than air.

How may a soap bubble show this to be true?— To the end of the bent tube from the hydrogen bottle fix a piece of rubber tube, and slip the other end of this over the stem of a common tobacco-pipe. When the air is all driven from the apparatus, put the bowl of the pipe into some soap solution, and let the hydrogen bottle blow a soap bubble. This bubble will not be long in breaking away from the pipe, and then it mounts, in a zig-zag path, to the ceiling of the room.

Fig. 6.

Does not the soap bubble tell us, as plainly as words could express it, that the hydrogen is lighter than air? The bubble has done much, but it cannot tell us the whole story. It cannot tell us that hydrogen is the lightest of all known substances, but this is true. It is *fourteen times* lighter than air; nothing else is so light.

Fig. 7.

What is a consequence of this lightness?—One consequence of this lightness of hydrogen is that it will not stay in any vessel that has even the smallest opening at the top, but it will not fall out of a vessel however wide it may be opened at the bottom. Hydrogen might be carried in a bucket if the bucket should be kept bottom upwards; the heavier air beneath would keep it from falling.

But these physical properties of hydrogen are not the most interesting which it possesses. We have seen that it is combustible; let us now

Describe an experiment to show its flame.—Instead of the bent tube in the neck of the hydrogen bottle, put a tall straight tube, the upper end of which is drawn to a point, so as to leave the opening small. Now let the acid be poured in upon the zinc; the rapid evolution of hydrogen will soon drive the air all from the bottle. *Not until this has been done,* touch the jet of escaping hydrogen with the flame of a match; it takes fire with slight explosion, and then continues to burn with a dull flame as long as the gas is supplied. (Fig. 8.) Let us look carefully, so as to be able to

Fig. 8.

Describe the flame of burning hydrogen.—We notice first of all that it gives a very feeble light, and that what there is appears to be of a bluish or perhaps of a delicate yellowish color. It has been lately said that this flame is entirely without color, and that the color usually seen is due to

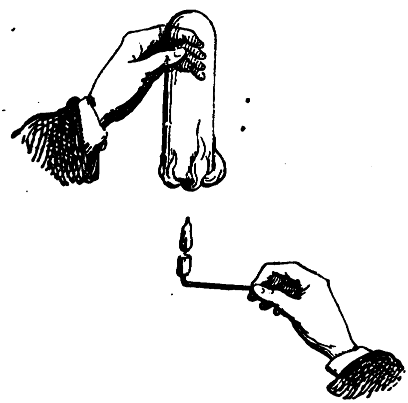
impurities in the gas. However this may be, and no doubt it is true so far as the yellow is concerned, we are not likely to get it in our experiments in such a way as not to show some color.

But what it lacks in light this flame seems to gain in heat. A common flame will outshine it, but no common flame of the same size can equal it as a source of heat.

We have been so busy thinking of the burning of the gas that we have forgotten to notice

What effect is produced on the flame which fires it? —This question is best answered by another experiment. We take a piece of taper or candle and fasten it upon the end of a wire. Now, lifting the jar of hydrogen from the cistern carefully, keeping its mouth downward, we plunge the lighted taper-test up into the gas. In Fig. 9 the candle is seen as if just to enter. The moment the tip of the flame touches the gas a quick explosion is heard as usual; the gas takes fire and burns quietly at the mouth of the jar, but the flame of the taper-test, on being pushed up into the jar *is extinguished:* not even a spark remains upon its wick. The hydrogen, which itself burns, put out the flame of the taper as quickly as water would have done. Indeed this is the only respect in which we discover any likeness of hydrogen to water, from which it is obtained.

Fig. 9.



How without water could we quench great fires? Who, then, would suspect that in water there is a substance so combustible as hydrogen gas?

Whenever we set fire to hydrogen in the air our ears are saluted with an explosion.

Describe an experiment to illustrate the explosibility of hydrogen.—A strong bottle with a wide mouth is provided with a thin cork having a hole through its centre. We fill the bottle about one third full of water and invert it in the cistern over the end of the tube leading from the hydrogen bottle. Hydrogen entering the bottle will drive water out. We cork the bottle while its neck is still under water, and then, covering the small hole, we take it from the cistern and stand it on the table. In the other hand take a long wire, to one end of which a match or taper has been fastened beforehand. Uncovering the hole in the cork, stepping back at the same time, quickly reach the flame of the match over and into the hole. A sound is heard like the report of a small pistol, and the cork is sent flying to some other part of the room.

Who would suspect that water could furnish us a gas more combustible than tinder, and when mixed with air, more explosive than gunpowder!

OXYGEN.

Whenever electricity, in our experiment, Fig. 4, gives us hydrogen, it gives us oxygen also, but we are not likely to get enough of it in this way to enable us to learn much of its curious character.

From what substance and how shall we obtain this gas?—A substance, called by chemists *potassic chlorate*, is able to furnish oxygen in great abundance. It is a white solid, but every ounce of it contains about two gallons of oxygen.

The picture (Fig 10) shows an arrangement of the apparatus used to get oxygen from potassic chlorate. At the left we see a flask, standing upon a small furnace. Into this flask the potassic chlorate, mixed with a small quantity of *black oxide of manganese*, is put. The flask is then tightly corked and a little water is poured in to fill the bend of the tall tube to serve as a kind of safety valve; sometimes this tube is not used. We notice next, the bent tube reaching over into and almost to the bottom of the water in a bottle, and then another reaching from this bottle over into the water of the cistern at the right.

Now when the potassic chlorate becomes intensely heated by the fire of the furnace, oxygen is set free. The gas passes through the bottle in which it is "washed," and then over to the cistern where it escapes. A receiver, filled with water and inverted over the end of the tube, catches the gas, and when filled, others may be put in its place until the material refuses to give up any more.

What are some of its physical properties?—Looking at the vessels full of this gas the sharpest eye can detect no appearance unlike what would be seen if they were full of hydrogen or air. Oxygen is as colorless and transparent as

they. It is also just as tasteless and odorless. Is there then no difference which it can show without chemical change? It certainly cannot be like both in weight. How shall we compare them? Nothing is more simple. Let us fill a jar with

Fig, 10.

oxygen and leave it standing with its open mouth upward on our table. Now, after some seconds let us lower a burning taper into the jar; the brightness of the flame assures us that oxygen is still there. Hydrogen would have left the jar quickly; oxygen must be heavier than it. Let us next fill a jar

with oxygen and hold it for a few seconds with its mouth downward. The lighted taper put into the jar then burns no more brightly than in air. The flame thus tells us that the oxygen has fallen out of the jar; it must be heavier than air.

Oxygen is sixteen times heavier than hydrogen and about 1.1 times heavier than air.

But while the physical properties of oxygen are so much like those of air and hydrogen, its chemical character is wonderfully different.

What are some of the chemical actions of oxygen?—Bodies burn in the air; in oxygen such bodies burn with greater vigor. Many bodies do not burn in air; some of these will burn with great splendor in oxygen.

Describe the experiment with a candle.—To speak first of those bodies which do burn in air. Let us take a piece of common candle; fasten it upon the end of a bent wire, Fig. 11; light it and sink the flame into a jar of oxygen; the flame instantly grows larger and brighter. Let us extinguish the flame and leave a little glowing spark upon its wick; the oxygen will instantly relight it.

Fig. 11.

The "battle for the flame" is an amusing contest. With care and skill it may be fought in this way:

A lighted candle stands upon a table between two boys. One of these, whom we will call *Oxy*, has his mouth filled to its utmost capacity with oxygen gas; the other, whom we may call *Airy*, has only air in his. Airy blows the candle and leaves only a glowing spark upon its wick. Oxy puffs upon it and the flame returns. Airy blows again and extinguishes the flame. Oxy gives another puff and relights it. Puff, puff; the flame expires and again revives until Airy leaves no spark upon the wick, or Oxy's gas is exhausted.

Describe the experiment with sulphur.—Sulphur burns feebly in air. Put some of this substance into a little

Fig. 12.

spoon; set it on fire and sink it into a jar of oxygen. Fig. 12. The sulphur will burst into beautiful combustion with purple flame.

Describe the experiment with Phosphorus. — Phosphorus burns in air with great vigor. Put a small piece of phosphorus into a spoon, sink it into a jar of oxygen and then touch it with the hot end of a wire. It breaks into flame, growing brighter until the eye is dazzled. One might almost as easily look at the bright sun at mid-day as at this flame of burning phosphorus. But it quickly dies and leaves the jar filled with vapor as white as milk.

Describe the experiment with iron.—Among bodies which do not burn in air, iron is a fine example of one which will burn freely in oxygen gas. Let a wire of this metal be tipped with wood. Let the wood be set on fire and then thrust into a jar of oxygen. The burning wood will set fire to the iron wire, which will rapidly burn with exceeding beauty. Or in place of the iron wire let a piece of steel watch-spring be used in the same way. Fig. 13. The steel will burn with a blinding light, filling the jar with glowing star-like sparks, and waste away almost as fast as a thread will disappear when one end is held in a lamp flame.

And now do not let us forget that this curious gas is one of the substances into which water was changed by electricity in our experiment. Who would suspect that out of water could come a substance so friendly to fire, that even iron and steel will burn in it more freely than tinder in air!

Fig. 13.

What is a compound?—Hydrogen and Oxygen, how different these substances from the water which yields them! *Hydrogen* is a very combustible gas; *oxygen* promotes the burning of other bodies in the highest degree, but *water* from which these gases may be obtained is the most inveterate foe to fire. Water is made up of these two substances so unlike itself. On this account it is called a compound.

A compound is a substance made up of two or more other substances and having properties very different from theirs.

Mention some other examples of compounds.—The milk-white vapor left in the jar after the brilliant combustion of phosphorus is a compound. Phosphorus is a waxy solid, oxygen a colorless gas, but when put together they produce the white vapor so different from themselves.

The red substance left after the burning of steel in oxygen is also a compound; it was made of oxygen and steel, but it is like neither of these in character.

What are elements?—Hydrogen has never been broken up into other sustances unlike itself; on this acccount it is called an element.

Oxygen has never yet yielded to any attempt of the chemist to decompose it, or, which means the same thing, to break it into other substances unlike itself. For this reason oxygen is called an element.

An element is a substance which has never yet been decomposed.

Give other examples.—Sulphur, when pure, has never been decomposed; it is an element. Phosphorus is an element for the same reason. Iron and copper, so common and useful; and gold and silver, so much more rare and precious, are able to resist every effort of the chemist to separate them into anything else, and may be noticed among familiar examples of elements.

What is analysis?—Our experiment with water (Fig. 4) was analysis. What we must now notice is this: by passing electricity through the fluid we broke it up or *decomposed* it, and by so doing we *learned* that water is *composed* of the two gases, hydrogen and oxygen.

Water can be decomposed in a great many other ways, and hydrogen and oxygen would be found to be its constituents in every case. No matter how it might be done, the process would be called an analysis.

An analysis is any process of decomposing a compound so as to learn its composition.

There is something more than we have yet noticed, and very important for us to know, about the composition of water. Let the experiment teach us what it is.

What more does the experiment teach?—Having the apparatus before us again (Fig. 14) we see the bubbling of the water in the tubes and the two gases collecting as before. But now after a little time, behold! how much more gas is caught in one tube than in the other! It is the hydrogen that is coming in most abundance.

Let us look more attentively and we see that the gas is filling the hydrogen tube just *twice as fast* as the other. We learned before that water consists of hydrogen and oxygen; we now find that *it contains just twice as much hydrogen as oxygen.* There is never a whit more of either of these gases by volume than the proportions of *two* to *one.*

But how is it when the gases are weighed instead

of being measured?—Very different. Hydrogen is so many times lighter than oxygen that the larger *bulk* of it *weighs* less than the smaller bulk of oxygen. The hydrogen from water weighs only *one-eighth* as much as the oxygen. Or to put it in other words: the proportions by weight are *one* of hydrogen to *eight* of oxygen.

Fig. 14.

What then is the composition of water?—The completed analysis teaches that this fluid is made up of hydrogen and oxygen, by volume, in proportions of 2 to 1, but by weight in proportions of 1 to 8, or, as the chemist oftener gives it, for a reason which we must not stop now to explain, 2 of hydrogen to 16 of oxygen.

These two gases are the only constituents of all *pure water* but they can never be found in it in any other proportions than those just stated.

Fig 15,

WATER AS WE FIND IT IN NATURE.

Is pure water to be found abundantly?—The most delicious water of our best springs is impure. Even the rain drop, which has never touched anything but the air through which it falls, is not pure water. Pure water is not to be found in nature. If found at all it is in the laboratory of the chemist who has carefully obtained it by artificial means.

We need to know *why* water is always impure and some-

thing about the nature of its impurities, but the facts cannot be stated fully in a single sentence nor even in a single page; let us study the subject step by step.

Describe the experiment.—Let us take a glass jar and fill it nearly full of colorless transparent water. Let us cover it with a piece of thin muslin and bind the muslin cover in its place by means of a piece of string. Let us put a spoonful of powdered cochineal upon the muslin cover and then let us pour slowly upon it some clear water. Very soon the water trickles through the muslin cover and falls into the water below. But how changed! Instead of the clear and colorless water, it comes through the muslin a *crimson* stream.

What has happened?—The water in passing through the cochineal broke up each little particle of that substance into pieces, perhaps a thousand times smaller still. These little pieces are so scattered through the water that, while not one of them can be seen, the multitude of them gives a crimson color to every part.

Now whenever a substance is so broken into minute pieces which cannot be seen and which will not settle when the water stands quietly, it is said to be *dissolved.* The water dissolved the cochineal. The red fluid below is a *solution* of cochineal in water.

Does water dissolve other solids?—Let common salt be used instead of the cochineal and the water that falls through the muslin cover may be as colorless as before. Has it, therefore, dissolved no salt? Let us taste it: we find that it has become brine. The water has *dissolved* the salt, and that which falls through is a *solution* of salt.

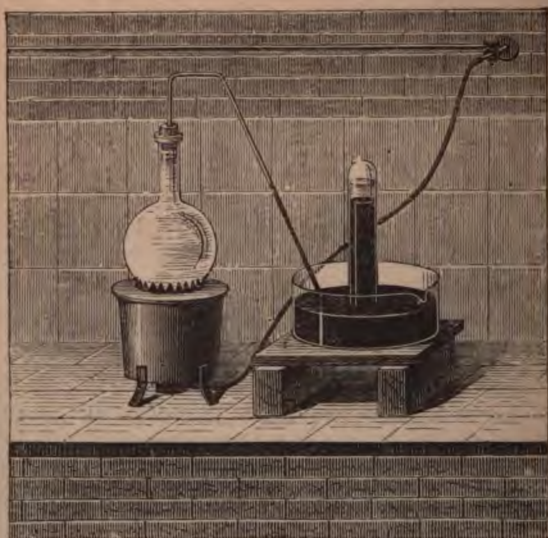
A vast number of other solids are more or less soluble in water. Only let water come in contact with them and they enter it in solution. Some of them give it color; others give no visible sign of their presence. The most colorless water may contain a great number and a great quantity of these dissolved impurities.

Nor is this all : water will dissolve gases.

Who would think that a considerable quantity of air is hiding among the molecules of a goblet of water !

Does water dissolve air ?—But let us put the limpid liquid into a glass flask and gently warm it. Little bubbles of gas will shortly be seen clinging to the bottom and sides of the vessel. More and more numerous and larger and larger they become, until, as the heat increases, they break away and escape at the surface of the water. These bubbles are bubbles of air. It was in solution in the water and the heat has driven it out. It may be caught in another vessel (Fig. 16) if desired.

Fig. 16.



Does water dissolve other gases ?—Many other gases are even more soluble than air. Ammonia gas is a re-

markable example : a cubic inch of water, when so cold as to be just ready to freeze, will dissolve more than a thousand cubic inches of ammonia gas!

The unpleasant gases arising from decaying animal and vegetable matter are ever ready to enter water and remain in solution when brought in contact with it.

Oxygen, hydrogen and many other gases not yet spoken of, may be dissolved in greater or less degree by water.

We are now prepared to explain the curious fact that *pure water* is not to be found in liquid form unless obtained by some artificial process.

What are the impurities of rain water ?—A drop of rain just starting from a cloud must be water very pure, but when we think of the journey it travels to reach the earth we can see how slight the chance of its remaining so. It falls through the air, and the air contains many gases which are soluble in water. Come as quickly as it may the little drop must take in some portion of these gases on its way, and when it touches earth it is not pure water. The impurities of rain-water are the gases of the atmosphere through which it falls.

What are the impurities of spring and river water ?—Once upon the earth the contamination of the water begins in earnest and goes swiftly forward. In passing through the soil and over rocks it meets with particles of salt, sometimes of saltpetre and of a hundred other substances which water may dissolve. Some of each of these is taken into itself, and when it issues as a spring, or flows toward the sea in rivulets or rivers, the water, clear and sparkling as it may be, retains them all.

The impurities of spring and river water are the soluble substances in the soil through which it has passed.

Are these impurities always the same ?—All soils do not contain the same substances ; on this account the impurities of different waters will not be alike. The *kind* of

impurity will depend upon the character of the soluble substances in the soil through which the water passes, and the *quantity* will depend upon the abundance of them in it.

What is mineral water?—In the waters of most springs no substance is dissolved in quantities large enough to make its presence distinctly known, but in others this is not so. When a water contains enough of any one thing to give it a peculiar taste it is called a *mineral water.*

Mineral springs take their names from the substance which is dissolved most largely in their waters. Sometimes it is common salt: they are then called *salt springs.* Sometimes it is a compound of iron: in this case the spring is called a *chalybeate* spring. Sometimes the compounds of sulphur are dissolved in large quantities: the spring which yields such water is called a *sulphur* spring.

Thus all water, be it in springs or wells, in rivers, lakes or seas, is more or less impure. Yet people do not hesitate to speak of water from these sources as being pure or impure.

What, then, is pure water?—If water is limpid, sweet, and contains no unhealthy substances, it is commonly called pure water, although it may contain many impurities which are not unpleasant. To call such water wholesome is more nearly correct than to call it pure.

To be really pure, water must contain nothing whatever in solution. It must be the compound of hydrogen and oxygen and nothing else.

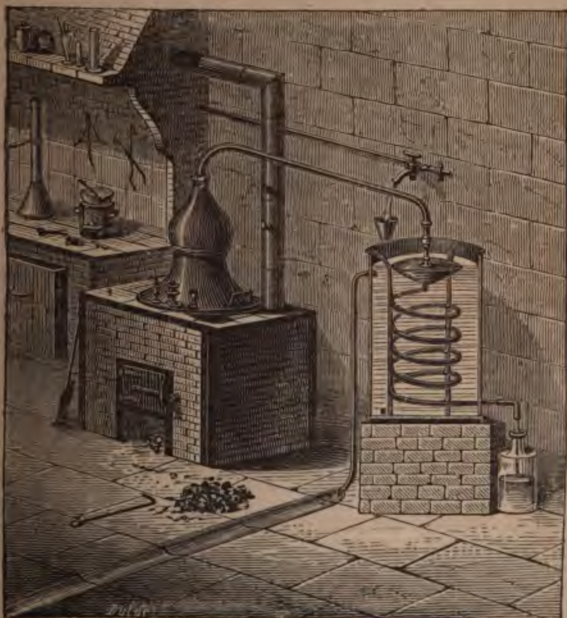
How may water be purified?—Water may be purified by boiling it. At first the heat will drive off the gaseous impurities with the steam. Let these go off into the air. After this the pure water will be driven away as steam while the impurities will be left in the vessel. Let the steam be caught and cooled again and pure water will be obtained.

But how shall this be done?—The picture (Fig. 17) will help us to understand the process. See at the left a vessel

with a long neck. It stands upon a furnace. The other end of its long neck is joined to a long tube which is coiled inside a large vessel. This vessel is kept full of cold water.

Now when the water boils the steam goes over through the long neck into the cold tube, in the vessel of cold water, where it is itself cooled down into water again. This water is nearly pure and it may be made still more so by boiling it a second time in the same way.

Fig 17.



What is this process called?—This method of purifying water is called *distillation*. Other liquids may be purified in the same way.

In what other way may water be purified?—Water by freezing is separated from its impurities. By melting ice which has been formed under most favorable circumstances, pure water may be obtained. Snow flakes, just fallen, are pure frozen water. Up in the cold atmosphere, the molecules

Fig. 18.

of water collect into little groups and cling together while they seek the ground. How curiously formed are these little groups! (Fig. 18.) Into them no impurity enters. But like everything else in contact with earth, they cannot long remain without contamination.

Fig. 19.

THE ATMOSPHERE.

What was once thought to be the nature of air?—Not one hundred years ago most men believed air to be an element. Men of science had said that air could not be decomposed, and no one knew how to prove them wrong.

Who proved that air is not an element?—But Lavoisier separated the air into parts consisting of two different kinds of gas, and so proved that it is not an element.

How did he do this?—By a most ingenious experiment. It was performed in the following way:

A small quantity of pure mercury was put into a glass flask which was placed upon a furnace. The flask had a long and slender glass neck which reached over into a vessel of mercury. Standing, mouth downward, in this vessel of mercury was a glass receiver containing air, and the neck of the flask was bent upward so as to reach up into it. The picture (Fig. 20) very well represents the apparatus thus arranged for this fine experiment.

Fig. 20.

When all was ready Lavoisier lighted the fire in the furnace and kept it burning all the time for twelve days! On the second he saw little red flakes of something swimming around on the surface of the mercury. For four or five days the quantity of this red substance increased while the quantity of air in the receiver diminished. For some days longer the heat was kept up, but no further change took place and this part of the work was done. He had less mercury and less air in the apparatus than at first, but the new red substance took the place of what was thus lost.

What was this red substance?—Lavoisier next put the red substance into a glass tube having a small neck reaching over to a cistern of mercury. Over the end of this neck a glass receiver, filled with mercury, was inverted. He applied a strong heat to the tube, when, lo! the red substance changed color—then began to waste away. Bubbles of colorless gas began to rise into the receiver and little globules of shining mercury to collect upon the inside of the tube above the heat. Finally the red substance disappeared completely and the action stopped.

This experiment proved that the red substance was a compound of mercury and the air-like gas in the receiver.

What was this air-like gas?—It was not air for, listen: "Having introduced a portion of this air into a glass tube, an inch in diameter, I plunged a candle therein; *it burned with a dazzling flame.*" The air-like gas was oxygen?

The red substance then must be a compound of mercury and oxygen.

Whence came this oxygen to combine with the mercury?—There was nothing but mercury and air in the apparatus when the red substance was made, but the mercury took oxygen; where could it get it but from the air? The air gave up a *part of itself* and that part was *oxygen.*

But what was the other part?—It was left in the receiver over the mercury cistern, (Fig. 20,) and looked like air, but on taking some of it into another vessel and plunging the candle into it the flame was put out as quickly as if it had been plunged into water. It could not be air, for air would have allowed the flame to live. It was the gas called *nitrogen.*

And so the hot mercury of Lavoisier had separated air into two things very unlike itself: it took away the *oxygen* and left the *nitrogen*, and proved that air is not an element but that it is made up of at least these two gases.

NITROGEN.

With oxygen we are a little acquainted, but what is the character of this other constituent of air? Let us get it from the air, but do not let us attempt to do this by heating mercury. What Lavoisier did in twelve days we are able now to do in as many minutes. Let us burn phosphorus instead of mercury.

How may phosphorus be used to take the oxygen from air?—A bit of phosphorus as large as a pea shall be put into a little shallow dish and floated upon the surface of water in a large basin. A large glass receiver shall be placed with its open mouth over the phosphorus and in the water

Fig. 21.

below. The phosphorus is thus shut in with the air of the receiver. (Fig. 21.)

When all is ready, take the stopper from the top of the receiver, set the phosphorus on fire by plunging a hot wire down to touch it, and then quickly return the stopper to its place. The phosphorus will burn violently with a beautiful flame, and the receiver will be quickly filled with the same milk-white vapor as was seen when phosphorus was burned in oxygen.

This white vapor is a compound of phosphorus and oxygen; the oxygen of the air has been taken away by the phosphorus to form it.

But how can we get rid of this vapor?—Nothing is more simple. It is soluble in water and if we allow it to stand quietly for a little while the water will take it all out for us. The nitrogen of the air will be left in the jar for us to study.

What are some of its properties? Let us examine it and we shall find that it is without color, without taste, without odor, and, if we cannot say without weight, we can say without as much weight as air possesses; it is about nine tenths as heavy as air when equal bulks of the two are compared.

What is its effect upon flame and life?—No fire can live in nitrogen gas. Plunge a candle flame into a jar filled with it and the light expires. Water could not quench it quicker.

And if we would know how it would affect us and all animals, were it to be breathed instead of air, we need only to look at the picture (Fig. 22) which shows how the life of a bird would be sacrificed if we were to try the cruel experiment of shutting it up in a jar of nitrogen.

Is nitrogen poisonous?—Yet nitrogen is not at all poisonous. We have taken it into our lungs with every breath, and must do so as long as life lasts. We are not injured by it. The bird (Fig. 22) was not killed by the nitrogen in the jar; it died because there was no oxygen there. *It is the*

oxygen of the air that affects our lives. Its absence causes aeath. Nitrogen has no power to support life, and on the other hand it is quite innocent of any action that can cause death.

Fig 22,

The atmosphere is for the most part made up of these two gases, oxygen and nitrogen. But the student of chemistry does not stop his study when he has learned what different *kinds* of matter are to be found in a substance. He next asks *how much* of each it contains.

What are the proportions of nitrogen and oxygen in air?—To answer this an experiment must be described. Let us suppose that the air to be examined contains nothing but oxygen and nitrogen. We may then learn their proportions very nearly by using the apparatus shown in Fig. 23.

The bent tube contains a *measured* quantity of air, say ten cubic inches, and its open end is covered by mercury in the cistern so that no air can enter—none get out. In the upper end a little metallic copper is placed ; this is to be heated by the lamp.

Fig. 23.

Now hot copper has a strong attraction for oxygen, and will slowly take it until no more is left in the tube. It cares nothing for nitrogen and will not take a particle of it.

At the end of the heating, when the oxygen is all combined with the copper, let the nitrogen be measured and eight cubic inches will be found. There were *ten* inches of air at first ; we have *eight* cubic inches of nitrogen left ; the other *two* inches must have been oxygen which the copper

has taken away. The experiment tells us, very plainly, that the air contains nitrogen and oxygen in the proportion of 4 to 1; *four fifths* being nitrogen and *one fifth* oxygen. In 100 cubic inches of air there are 80 cubic inches of nitrogen.

These results are very near the truth, but not near enough to satisfy a chemist. Would you know the most exact results? Here they are:

One hundred cubic inches of air contain of

Oxygen, 20.8.
Nitrogen, 79.2.

What are the relative weights?—When the gases are weighed instead of being measured the ratio is different.

One hundred ounces or other parts of air contain, of

Oxygen, 23.0.
Nitrogen, 77.0.

But it is now time that we notice that oxygen and nitrogen are not the only substances contained in the atmosphere. There are many other things in small quantities, almost too small to be compared with them, yet altogether too important to be forgotten or overlooked.

WATER-VAPOR.

How do we know that air contains water-vapor?—The ice-water pitcher in a summer day tells us that there is water in the air, by covering itself with drops like dew. The pitcher is colder than the air and condenses the vapor into water upon its surface.

The dew drops sparkling on the grass and flowers in the morning sunlight, are telling us the same story. The ground becomes colder than the air above it and condenses the vapor of the air to dew.

The hoar frost is another evidence of the same kind. The vapor of the air, first condensed into water by the cold

ground, grows colder and colder, until it is frozen and covers every object with a delicate garment of ice.

Is this water-vapor always present in the air?—This water-vapor is never absent. We cannot see it, yet the dryest air contains it.

The dew cannot be seen long after it feels the sunshine; what becomes of it? It goes into the atmosphere and there it stays, during the sunshine, in the form of invisible vapor. Water is passing into vapor every moment from every river, lake and sea. This vapor cannot be seen; it is a part of the invisible air. It makes its appearance only when cooled. It may then be seen, sometimes as fogs, sometimes as clouds, sometimes as dew-drops, sometimes as snow-flakes.

How much of this vapor does air contain?—The quantity of this water-vapor in the air is all the time changing. There is a certain amount which air *may* hold at any given temperature, and the only way to make it able to take any more is to heat it.

But the atmosphere seldom has all that it might hold. At 60° F. the quantity will be usually found between $\frac{1}{80}$ and $\frac{1}{100}$ of the bulk of the air.

CARBONIC DIOXIDE.

How do we know that air contains anything beside oxygen, nitrogen and water-vapor?—The air is able to do some things that neither oxygen, nitrogen nor water-vapor can. There must be something else in it.

Lime water will most easily show us such an action. Lime water is nothing but a clear solution of lime in water; it is as limpid as water itself. Not one of the three substances named, nor all of them together, can make any change in the appearance of lime water. But let a dish containing this fluid be left quietly standing for a few hours, and a thin white crust will be seen upon the surface of the water.

What is this other substance in the air?—Now there is but one substance that will act upon lime water in this way; it is *carbonic dioxide.*

What fraction of the air is carbonic dioxide?—Sometimes as much as $\frac{1}{1000}$ of the air is carbonic dioxide; at other times or places there may be no more than $\frac{1}{5000}$. Perhaps the average proportion may be $\frac{1}{2500}$.

So small a quantity as *one* cubic inch of this gas in *twenty-five hundred* cubic inches of air seems, at first thought, too small to be worthy of notice. It is not so. Small as it seems it is yet one of the most important substances in the atmosphere. Plants cannot grow without it. It promotes the growth of plants as oxygen promotes that of animals. The vegetation of a fertile earth may constantly remind us of the vital importance of the minute proportion of the carbonic dioxide in the atmosphere. Let us learn more about this wonderful gas.

How shall we obtain it for examination?—Not from the air; it is there in too small proportion. Marble contains it in large proportion and is ready to give it up when properly asked for it.

Let some small fragments of marble be put into a bottle such as may be seen at the right in Fig. 5. Let a little water be poured in upon them and then some hydrochloric acid. The acid attacks the marble; a violent foaming instantly begins, and a stream of gas flows rapidly through the bent tube to be caught in the receiver at the left. This gas is *carbonic dioxide,* commonly called *carbonic acid.*

How can we know it to be this gas?—By placing a dish of lime water in a jar of this gas. It will not be long before the same kind of a white crust may be seen upon it as was seen when the fluid had been exposed to air.

Or let a stream of the gas bubble through the lime water, and behold, the fluid so clear before, quickly becomes "milky"

in every part. We cannot see carbonic dioxide, but lime water is always ready to tell us whether it is present.

Fig. 24.

What are some of its properties?—Carbonic dioxide is a colorless gas, so heavy that it may be poured from one vessel to another almost like water.

Fig. 25.

See in the picture (Fig. 25) an experiment with this gas. The vessel in the hand is full of it, and it is being poured down upon the small flame of the taper hanging inside the other. It will fall upon the flame like water, and *put it out.*

Learn from this that carbonic dioxide is much heavier than air and that it will extinguish fire.

What else will it extinguish?—Life! No animal can live where much carbonic dioxide is found. (Fig. 24.) In Java there is a place called the *Valley of Death.* In this low

Fig. 26.

The Valley of Death (Java).

place this gas collects in more than usual quantities, and it is said that the ground is strewed with the bones of birds and beasts which perish by breathing it.

This gas sometimes collects in mines, and its effect upon the miners may be partly judged by the name they give it; they call it *choke-damp.*

It is dangerous to descend into deep wells or pits of any kind without first finding out whether this poisonous substance has collected there. But how shall we find out? Nothing is easier. Just lower a lighted candle to the bottom. If it continues to burn freely, the gas cannot be largely present, but if it be extinguished, so our lives would be.

Will water dissolve carbonic dioxide?—Suppose we have a bottle partly filled with water and the part above the water filled with this gas, and suppose that we cover the mouth

of the bottle closely with the hand so that no air can get in and nothing can get out, and that we shake the bottle violently. After the agitation will there be any change in its contents? We shall be able to *see* none. But, after the fluid has become quiet, let us take the hand suddenly away from the mouth of the bottle. Something will be *heard;* the sound will be caused by air rushing violently into the bottle where the carbonic dioxide was before. This gas has been taken away, else the air could not enter; what has become of it?

The experiment shows that carbonic dioxide is soluble in water.

How much of this gas will water dissolve?—Not always the same proportion; it depends upon the temperature and the pressure under which the solution takes place. The colder the fluid the more gas will be dissolved. The greater the pressure upon it the more gas water will receive.

At ordinary temperature water may dissolve about *its own volume* of carbonic dioxide. A cubic inch of water, for example, may dissolve a cubic inch of the gas.

But is there always the same quantity of gas in a cubic inch at ordinary temperatures? By no means. The real quantity of a substance is represented by its volume. Put it under double pressure and there will be just twice as much gas by weight in a cubic inch, or under ten times the pressure and there will be ten times as much in the same space. The weight of the gas in the cubic inch will be as the pressure. But the cubic inch of water at ordinary temperature will dissolve the cubic inch of gas, no matter how much by weight there may be in that volume. So that the weight of carbonic dioxide which the water can dissolve at ordinary temperature will be as the pressure upon it.

Is the solution of this gas to be found in nature?—Carbonic dioxide is to be found in solution almost everywhere. Nearly all waters contain this gas, but the quantity in solution is generally small. But, on the other hand, it is sometimes

OZOUF APPARATUS FOR MANUFACTURE OF SELTZER WATER.

very great. Some spring waters contain so much of this gas that on reaching the surface of the earth and being exposed to the atmosphere they let it escape in bubbles. Many of the most noted mineral springs in the world are of this character. Those of Seltz and Ems in Germany are famous, and, in our own country, those of Saratoga are noted for their health-giving qualities. The sparkling and refreshing character of these waters is due, very much, to the large proportion of carbonic dioxide which they hold in solution.

What is soda water?—The refreshing summer drink known as "soda water" is nothing but common water holding carbonic dioxide in solution. Real soda water contains a little soda in the solution with the gas, but that which is so well known as soda water often contains no soda.

Water so highly charged with carbonic dioxide is sometimes also called *Seltzer* water. The true Seltzer water comes from the celebrated spring of this name and contains many other things beside carbonic dioxide in solution. These artificial waters are greatly inferior to those which the earth pours out in such abundance from her own bosom. Yet they are wholesome and everywhere highly esteemed; on this account it is interesting to know something of their character and manufacture.

The violent foaming of these waters, when drawn from the "fountain," is due to the escape of carbonic dioxide gas which they have been made to dissolve by high pressure, but which they cannot hold when under only the pressure of the atmosphere.

How have they been so highly charged with gas?—One form of apparatus by which soda or seltzer water is made is shown in the picture. Let us study it.

See, at the left in the engraving, three vessels standing upon a table. Into the first of these some marble and some acid are put, by which the gas will be set free in large quantities. By passing through the other two of these cylinders

and then through the smaller vessel, to be seen above and a little toward the right, the gas is thoroughly washed and made pure. The purified gas next passes into a gasometer.

Notice next in the picture the young man so laboriously turning a large wheel. By turning this wheel he pumps the gas out from the bottom of the gasometer and forces it up with water into a globe-like reservoir. As more and more of the gas is pumped in, it becomes more and more compressed, and when the pressure has run up to as much as ten or twelve atmospheres the water is sufficiently "charged" and may be drawn off into bottles.

For this purpose a lead pipe leads the water over to the bottling stand. The picture shows how the bottling is done. The bottle being fastened over the end of the pipe, a man holds it in one hand while he opens a valve in the pipe with the other. The water instantly spouts into the bottle and fills it. The bottle is then tightly closed by a cork, firmly bound, and the seltzer water is ready for market.

What is the composition of carbonic dioxide?—The following experiment will tell us what this gas is composed of. Let us have a jar filled with oxygen gas. Let us take a bit of well burned charcoal, fasten it to the end of a wire, set it on fire and then thrust it down into the oxygen. (Fig. 13.) A brilliant combustion instantly begins, and the charcoal wastes away until either it or the oxygen is exhausted. The jar is still full of gas; what is it? Lower into it a lighted taper; the flame is instantly extinguished. Pour into it a little lime water; it becomes milky at once. We are convinced that carbonic dioxide has been made in the experiment.

But of what? Oxygen and charcoal are the only things used; they have disappeared and in their stead we have carbonic dioxide. Is it not very plain that this gas is made up of these two substances? But charcoal is one of the best forms of what the chemist calls *carbon*.

We thus learn that carbonic dioxide is composed of oxygen and carbon.

Is it a compound of these two things?—To answer this question we must remember that a compound is a substance whose properties are not the same as those of its constituents. It is easy to name properties of carbonic dioxide which are very unlike those of either oxygen or carbon, and we must therefore call it a compound.

THE ATMOSPHERE A MIXTURE.

What are the constituents of the atmosphere?—Oxygen, nitrogen, water-vapor and carbonic dioxide are the important constituents of the atmosphere. We need not now stop to notice several other substances which, though generally present, exist in *only* minute proportions and which, so far as we know, are of far less importance.

Are the properties of the atmosphere like those of its constituents?—The properties of the constituents of the air are to be easily detected in the atmosphere itself. Thus:

The oxygen in the atmosphere causes bodies to burn; it would make them burn with terrible vigor if the nitrogen were not present to check it:

The nitrogen checks the combustion of bodies in air; it would extinguish it altogether if the oxygen were not present:

The water-vapor in the atmosphere condenses to water by being cooled, just as any other water-vapor will do:

The carbonic dioxide of the atmosphere makes lime water turbid just as the same gas from marble will do.

What is here particularly worthy of notice?—A very important fact. It is this. The oxygen, nitrogen, water-vapor and carbonic dioxide when together to make up the atmosphere show the same properties as when they are sep-

arate. The atmosphere, then, is not a compound of these substances; it is a *mixture* of them.

What then is a mixture?—A mixture is a substance made up of two or more others, each of which retains its characteristic properties.

We should be careful to see very clearly the difference between chemical compounds and mixtures. We have said that water is a *compound;* we now say that air is a *mixture.* Why this difference in name? In water, oxygen and hydrogen are so *combined* that they become a new thing in which their properties cannot be found at all—a *compound.* In air, oxygen, nitrogen and the others are so *mingled* that they form a new thing in which their properties are preserved—a *mixture.* To produce a compound a *chemical* change must occur; to produce a mixture, only some *physical* change is needed.

Are the constituents of the atmosphere uniformly mixed?—Air has been analyzed many times, and the relative proportions of its constituents are always very nearly the same. From the tops of mountains and from the low places of the earth, the mixture is found to contain all its constituents and in about the same relative quantities. This is a curious fact, as we shall see.

How do the constituents of air compare in weight?—No two of the constituents of the atmosphere have equal weights when compared in equal bulks. Carbonic dioxide is the heaviest; nitrogen is the lightest. Oxygen is much lighter than the first named and much heavier than the last.

Would this lead us to expect them to be uniformly mixed in the atmosphere?—This difference in weight would lead us to expect that the constituents of air would not be uniformly mixed. Let us see: Suppose that into a tall glass jar we put some mercury, some water and some oil, and then that we shake them well together; would they stay uniformly mixed? No one would expect it. A few minutes' quiet standing would spoil all the effects of the shaking. The

heavy mercury would settle to the bottom of the jar, the lighter water would form a layer above it, and the lightest of all, the oil, would lie upon the top of the water. (Fig. 28.) The attraction of gravitation is trying with all its power to pull the heaviest substance to the lowest level. Is it not a curious fact, then, that the heaviest carbonic dioxide, the lighter oxygen, and the lightest nitrogen are uniformly mixed in the atmosphere? Why are they not arranged in layers with the lightest at the top?

Fig. 28.

Why do they remain uniformly mixed?—Experiments have shown that gases in contact with each other cannot be kept separate.

Fill the lower half of a tall jar with heavy carbonic dioxide, and the upper half with hydrogen, which, we must remember, is the lightest of all gases. Let the jar be tightly closed and allowed to stand for a while at rest. It will then be found that the two gases are thoroughly mixed throughout the jar. The heavy carbonic dioxide has gone up and the light hydrogen has gone down! They have disobeyed the law of gravitation in order to mix with each other.

What is this action called?—This mingling of gases when they are simply brought in contact with each other is called *the diffusion of gases.*

The attraction of gravitation would arrange the gases of the atmosphere in layers, but the principle of *diffusion* requires that they shall be uniformly mingled in every part.

COMBUSTION.

Combustion is one of the most common and useful phenomena in every-day life. But what is combustion? What is the fire that warms us; what is the flame that gives us light? Fire, the ancients thought to be an element; they knew nothing of its nature. Fire, chemists now tell us, has no material existence. But the story is a long one; let us begin it by trying an experiment.

Fig. 29.

Describe the experiment shown in Fig. 29.—Hydrogen gas is set free in the bottle seen at the left in the picture. It passes over through the bent tube to the bottom of a tall upright jar. This jar contains some *calcic chloride*, a substance which cares nothing for hydrogen but which has a very

strong attraction for water. The gas, passing out at the top of the jar, will be *thoroughly dry*. Finally the hydrogen issues from the other end of the bent tube reaching from the top of the drying-jar, and is set on fire. A cold glass vessel is then brought down over the flame of burning hydrogen.

What is the result? Instantly the walls of the cold vessel are dimmed with dew! The dew rapidly accumulates and collects into little globules. The little globules, grown larger and larger, at length trickle down the sloping sides of the vessel and slowly drop from its mouth.

What does this experiment teach?—This experiment tells us that the burning of hydrogen is simply the *chemical union of this gas with oxygen.*

How does it teach us this? In this way: It *shows* us that water is produced by burning hydrogen in air. We *know*, already, that water consists of hydrogen and oxygen; and now, if we put together what we *see*, and what we *know already*, we must say that burning hydrogen is *hydrogen* which is *combining* with *oxygen.*

Where does it get this oxygen with which it forms water?—The answer is ready. The air furnishes it. But if the air is giving up its oxygen to the flame, its nitrogen must be left behind. Nitrogen takes no part in producing the flame.

What occurs when carbon burns?—When a piece of charcoal burns in air it very gradually wastes away and carbonic dioxide is formed. Now carbonic dioxide is a compound of carbon and oxygen, so the charcoal, in burning, must have taken the oxygen from the air. The combustion of charcoal seems to be nothing more than the *chemical action* of carbon and oxygen.

Of what do most fuels consist?—Now carbon and hydrogen are the chief constituents of nearly all kinds of fuel. When a fuel burns, the oxygen of the air acts upon

these two substances very much in the same way as it does when they are not combined.

What then takes place when a candle burns?—The wax of the candle is a compound of hydrogen and oxygen. The heat decomposes it, and then the hydrogen and the carbon separately burn.

What, then, will be produced? Is it not very easy to tell, knowing what we have just learned? When hydrogen burns, water is formed; and when carbon burns, carbonic dioxide is formed. Water and carbonic dioxide must be produced by the burning candle.

One thing more ought to be noticed. The air, giving its oxygen to the flame, is left with less of it and more of nitrogen, and if the burning could go on in a limited supply of air long enough, the oxygen would be exhausted and the flame would be compelled to die.

Can these facts be proved by experiment?—Let us now see whether a burning candle does, actually, take oxygen, form water and carbonic dioxide, and finally expire, as we have argued that it will.

Fig. 30.

We will take a candle, set its wick on fire and stand it upon a plate, and then invert a glass jar over it. (Fig. 30.) The candle is now burning in a limited supply of air, and whatever is formed will stay in the jar. The flame soon begins to lessen; dimmer and more dim it becomes, when, while we still look at it, it expires altogether.

Now notice; the sides of the jar are covered with *moisture*. The flame has given us water, as we thought it would.

Let us pour a little lime water into the jar; it becomes tur-

bid at once, showing that carbonic dioxide is also formed. In all respects the experiment has fulfilled our prediction.

Do the same things occur in other cases of combustion?—The candle flame teaches what takes place in all ordinary cases of fire.

When wood burns, it is decomposed. Its carbon and its hydrogen take oxygen from the air and form carbonic dioxide and water-vapor; and could the smoke, passing up chimney, be tested, these two substances would always be found in it.

In lighting a gas jet what does the heat of the match do?—A jet of gas, as that from a chandelier for example, escaping into the air, shows no signs of "taking fire," but touch it with a match-flame, and it instantly springs into vivid combustion. What has the match done? It has simply *heated the gas.* Illuminating gas will not burn until it has a temperature of about 1000° F., and when the fire of the match has heated the jet up to this temperature it bursts into flame.

What is this temperature called?—The temperature at which a substance begins to burn in air is called its "kindling point." The kindling point of most of our ordinary fuels is about 1000° F., but some other things begin to burn at a much lower temperature. Phosphorus, for example, whose brilliant combustion in oxygen gas we cannot forget, kindles at a temperature little higher than that of our fingers when we handle it.

The kindling point of a substance is the temperature at which it may begin to burn.

In lighting a gas jet the match-flame is needed only to heat it up to its kindling point.

In lighting a spirit lamp what does the heat of the match do?—Let the wick of an alcohol lamp be uncovered; no signs of flame are to be seen, but let a match-flame touch it, and very quickly a flame appears. Now the wick, to begin with, is wet with the liquid alcohol. The heat of the match

changes this liquid into vapor, and then quickly *heats this vapor up to its kindling point.* When this double work is done the flame appears.

The alcohol is in the gaseous form before it burns with a flame.

In lighting a candle what does the heat of the match do?—We will suppose, next, that we have a candle which has been lighted and partly burned on some previous occasion. Its wick is saturated with cold and solid wax. We touch it with a match-flame. We notice that it takes more time to fire it than it does a spirit lamp or a gas jet. The match has more work to do. It first *melts the wax ;* it next *changes it into vapor ;* and then, finally, it *heats the vapor up to its kindling point.* All this threefold work being done the candle flame appears. The wax is in the form of gas when it burns with flame.

In what condition must a fuel be to burn with a flame?—The wax of the candle, and the alcohol of the lamp, are changed into gases before any flame is seen. *Whatever burns with a flame must be, at that moment, in a gaseous state.*

Why does wood burn with flame?—Wood burns with flame because there are substances in it which the heat of the fire can change into gases. The burning of these gases, and not of the solid wood, gives the beautiful blaze which, in an open fire-place—now, alas! too rare—so cheerfully warms and lights the sitting-room, however cold and dark the winter evening may be.

Why does hard coal burn without flame?—Hard coal is made up almost entirely of *solid* carbon, which no furnace heat can change into *gas.* As there are no gases first made by the heat, so there can be no flame produced in the burning.

The heat by which our houses are warmed and the light by which they are illuminated are, let us remember, produced

by combustion. We cannot describe the condition of mankind, as it would be, if artificial heat and light could not be obtained. All the comforts of life, if not the continuance of life itself, are due to the influence of artificial heat and light. The chemistry of flame is too important a subject to leave before we have learned more about the production of heat and light. Let us begin by studying the hottest flame that we can get.

What is the hottest kind of flame?—The hottest kind of flame is called the *oxy-hydrogen flame.* It has this name because it is produced by the burning of oxygen and hydrogen gases.

Fig. 31.

This flame is so hot that if we hold the end of a steel watch-spring in it, the spring will burn almost as fast as a thread of cotton will burn when held in a lamp flame, throwing off, at the same time, a host of the most brilliant star-like sparks and a blinding light.

Platinum, a metal almost as precious as gold, will not melt in a furnace, but yields when attacked by the furious oxy-hydrogen flame.

The picture will teach us how this intense flame is produced, and at the same time show us how it has been used to melt platinum.

How is the oxy-hydrogen flame produced?—The two gases are brought in separate tubes, shown at the left in the cut,

to what is called the *blow-pipe.* This is made by putting one metallic tube right inside another larger one ; see it represented, vertically, at the top of the picture. The oxygen flows through the inside tube, the hydrogen through the outside tube, and both come out at the end of the jet together. Then they are set on fire and their flame is the well known oxy-hydrogen flame.

How is it used to melt platinum ?—The platinum to be melted is put into a vessel made of quicklime, (see it in the centre of the picture,) and this crucible, as it is called, is put into a sort of furnace with thick walls of lime. The oxy-hydrogen jet is put through a hole in the top of this furnace, and the flame wraps the little crucible in the most intense heat. The platinum quickly gives up to it and may then be run into moulds.

Is there anything peculiar about this flame ?—The oxy-hydrogen flame is not like common flames. Let us particularly notice one difference. *The burning gases are thoroughly mixed together* in this flame; this is not the case in common flames. When the gases are thoroughly mixed they can unite much faster than when they are not. Now *the intensity of the heat* in a flame *depends on the rapidity of the combustion.* This is one reason why the oxy-hydrogen flame is so intensely hot.

But what of its light ?—Its light is more feeble than that of an old fashioned candle ! This flame, so valuable for heat, is entirely useless for light.

What may we do to make it give light ?—Let a piece of quicklime be held in this hot, but almost lightless flame, and, lo ! a most dazzling light springs from it. This light, with one exception, is the most powerful light that can be made by artificial means. It has several names. It is called the *lime light* because it is glowing lime that shines. It is called the *oxy-hydrogen light* because the oxy-hydrogen flame heats the glowing lime. It is called the *Drummond light,*

sometimes, because it was first made by a man by the name of Drummond.

What two things may we notice about this light?—Let us notice that to produce this light there is, *first*, the intense heat of the oxy-hydrogen flame, and, *second*, a substance, lime, which the heat cannot vaporize nor melt.

The heat of the flame makes the lime white-hot, and it glows with a blinding light. Many other things might be used in place of the lime with the same result.

Whenever this condition can be secured in flame, the flame will be a light-giving flame. Let us see how it is secured in the flame of a candle.

Is there anything in the candle flame which heat cannot melt?—The wax of which the candle is made contains hydrogen and carbon, and we have already noticed that these things take oxygen separately when the candle burns. Now there are two curious facts about this. The first is that when hydrogen and carbon are offered to oxygen at the same time, the oxygen will take the hydrogen first; the second is that *carbon is a substance which no heat can melt.*

Is it the carbon which shines in the candle flame?—These two curious facts help us to see how the light of the candle is produced. The vapor of the wax is decomposed into hydrogen and carbon. The oxygen of the air first takes hydrogen and their union gives great heat. The *particles* of *carbon* are made white-hot by this heat and shine with a bright light.

Then what becomes of these solid particles?—Another curious fact must now be noticed. When the carbon particles become very hot the oxygen has a strong attraction for them as well as for those of hydrogen, and will combine with them to make carbonic dioxide.

So in the candle flame the carbon particles heated white-hot shine for a *moment* only, and are then seized by the oxygen, changed into carbonic dioxide and rendered invisible,

while a new set instantly takes their places. Thus each particle shines but an instant, yet the light of the candle continues. (See TEXT-BOOK OF CHEMISTRY, p. 169.)

What is the dark centre of a candle flame?—We have all noticed the dark centre of a candle flame, and have sometimes wondered, perhaps, why there should be this darkness in the midst of its light. Just remember what has been learned about the flame being a jet of burning gas, or let us go back even further than that and start our explanation with wax itself.

Fig. 32.

Well, first, we have in the burning candle a little cup of melted wax at the top. This liquid rises among the pores of the wick up to the flame and is there changed into gas, and this gas rises, as a sort of jet, into the air. But touching this gas jet, on all sides, is the oxygen of the air, and where the gas and the oxygen are together, there the burning goes on.

But where are they together?—Only *around the outside of the gas jet*, rising from the wick. There is no oxygen in the centre of the flame and so there can be no burning going on there. The dark space around the wick is filled with hot gas without oxygen. There is no combustion in there. Hold a piece of white paper across the flame a moment and see (Fig. 33) that it will not be burned in the centre.

Where does the combustion take place?—The paper is burned in the shape of a ring. The combustion goes on all around the outside surface of the gas jet, in what appears the luminous part of the flame. How unlike the action in a heat-flame!

Wherein does this differ from what goes on in a heat-flame ?—In a heat-flame the combustion is going on in every part of the gas jet; in this light-flame the combustion goes on only upon the surface.

Fig. 33.

To produce heat to the best advantage, the air or oxygen must be *mixed with* the burning gas; to produce light to the best advantage the air or oxygen must only be allowed to *come in contact with the surface of the burning gas jet.*

Why is a flat wick better than a round one in the lamp ?—The gas rising from a flat wick will be spread out into a sort of sheet, and have a *larger surface* than if the wick were round. This lets a large amount of air come in contact with the gas, and the light is much increased.

This illustrates the important principle which is kept in view in the making of lamps for illuminating our dwellings.

What is the principle ? *Obtain a full supply of air in contact with as large a surface of the burning gas as possible.*

To do this, the burner of a chandelier is made so as to spread the illuminating gas out into a wide fan-shaped sheet.

The Argand burner does the same thing in another way. Its wick is cylindrical and air is made to pass through the inside of it. The inside and the outside together form a large surface. By using a chimney a "draught" is made by which very much more air than otherwise would, is made to pass over the surface of the flame.

By securing a large surface and a full supply of air to the flame the best light will be produced.

RESPIRATION.

Without air no life exists. Animals and plants need the gases of the atmosphere as much as they need food and soil. Without food an animal starves; without air its death would come still more quickly. Pluck its roots from the soil and a plant withers and dies; give it the most fertile soil but take away the air and its death is just as certain.

Animals and plants are able to take the air into their bodies and then to throw it out again. This act is called *respiration.* Let us now study the respiration of men and animals.

What is taken into the lungs?—We breathe the air, but the air is a mixture of nitrogen, oxygen, water-vapor and carbonic dioxide, with very minute quantities of some other gases. These, then, are the things that enter the lungs.

What is thrown out of the lungs? To answer this question let us make experiments.

How shall we show that water-vapor is exhaled?—Let us take a very dry and clean glass jar, and breathe into it; its walls are at once covered with dew. Hence water-vapor is thrown out in the breath.

Indeed we have seen what would teach us this, a hundred times, no doubt. In a cold winter morning every breath looks like a cloud of steam. We *see* the moisture of the breath at such times, but, really, there is no more present then than at other times. The cold air condenses it and makes it visible.

How may we show that carbonic dioxide is exhaled?—Let us take a glass tube or a straw, and, with one end in the mouth and the other in a goblet of lime water, let us make our breath bubble through the transparent liquid. It is transparent no longer; it is almost as white as milk. What is the meaning of this? The lime water tells us that carbonic dioxide is thrown out with the breath.

What besides water-vapor and carbonic dioxide is exhaled ?—The picture shows how we may make a curious experiment to answer this question. Let us carefully study it.

Fig. 34.

In the first place there is a glass jar full of air standing in a vessel of water. In the second place there is a tall jar containing *caustic potash* connected with the top of this air-jar. In the third place there is he who breathes this air, with his lips at the end of a tube from the top of the potash jar. The air in the jar may be drawn into the lungs and then returned to the jar. This is to be done two or three times. In going back and forth between the jar and the lips, the air must each time pass over the caustic potash in the tube. This potash has a strong attraction for water, and for carbonic dioxide too, so what will this potash do but *take all of both these things out of the breath.* And yet there is found to be a very large quantity of gas left in the jar.

Now what gas is this? A lighted taper will tell us, if we open the jar and sink the flame into it. The flame goes out at once, showing that the gas is nitrogen.

See then how wonderfully the air we breathe is changed during the little time it stays in the lungs! Let us make

this change still more distinctly known by bringing the two conditions of the air in stronger contrast.

What enters the lungs?	*What is thrown out from them?*
Much nitrogen.	Much nitrogen.
Much oxygen.	Little oxygen.
Little water-vapor.	Much water-vapor.
Little carbonic dioxide.	Much carbonic dioxide.

What then is taken out of the air?—Much oxygen enters; little comes out. The oxygen of the air is being used up in the process of breathing.

What is produced?—Little water-vapor enters; much more comes out. This excess must be produced in the body. So, also, little carbonic dioxide enters, but much returns, and we must say that this substance is produced in the body.

Can we now see what becomes of the oxygen which is taken from the air?—Now water cannot be produced without oxygen; nor can carbonic dioxide. We find that the oxygen of the air is gone and that these other things have taken its place. Is it not very natural to say that the oxygen has been used up in making the water-vapor and carbonic dioxide, which are formed?

This accounts for the disappearance of the oxygen, but there is something more to be noticed. Hydrogen and carbon are also needed in order to produce water and carbonic dioxide.

Where do the hydrogen and carbon come from?—They cannot come from the air that enters the body; they must be furnished by the body itself. There is no other source.

In what part of the body does the oxygen find them?—Not in the lungs alone do the oxygen, hydrogen and carbon meet. They are meeting, molecule with molecule, in every part of the entire body.

How is this brought about?—It is a most wonderful action, and we cannot now explain it all. The study of physiology will make it plainer, but the following are some of the facts:

The air goes into the lung, and its oxygen passes through the pores of the delicate membrane, of which the lung is made, *into the blood*. With the blood, as it goes from the lungs, this oxygen is carried to every part of the whole body. It is while in the blood, going from place to place, that the oxygen meets the hydrogen and the carbon.

But how came they in the blood?—Every part of our bodies is constantly wearing out. You cannot move a finger without some of its particles being worn away! You cannot step without some of the particles of the limbs being worn out. Every breath, every motion, every thought, renders useless some portions of the parts of the body which are acting at the time.

These worn-out particles are all the time going into the blood that flows along where they are. They consist chiefly of hydrogen and carbon, and it is from these worn-out particles of our bodies that the oxygen gets hydrogen and carbon to form the water-vapor and the carbonic dioxide which are thrown out at every breath.

Is this process important?—Life itself depends upon this process. These waste particles are the impurities of the blood, and they must be taken out or death will quickly come. As long as oxygen is regularly supplied to the lungs it will change these impurities into water and carbonic dioxide, and, in these forms, they will be thrown out in the breath.

Are these the only substances exhaled?—These two substances seem to be the most abundant substances thrown out in the breath, but they are by no means the only ones. Many other impurities are exhaled at the same time. Some of these are very offensive, and all of them are very injurious to health if taken again into the lungs.

In what way is air being spoiled by breathing?—Every breath takes oxygen from the air, but oxygen is the only thing in air that can purify the blood. By the loss of its oxygen the air is being spoiled. Once breathed, it is, on this account, unfit to be breathed again.

Is it spoiled in any other way?—This is only one way, and that not the worst, in which the act of breathing spoils the air. Every breath is polluting all the air into which it is thrown, with the impurities of the blood. Air without its oxygen would not be poisonous nor filthy, but air with the abundant impurities thrown into it with the breath is both poisonous and filthy. Were the impurities of air, which has been breathed, to be seen, we would shun such atmosphere as we now shun the water of a stagnant pool. Ought we to shun it less because they are invisible?

What then seems to be necessary?—It must be necessary to change the air in the rooms of our houses very often and very thoroughly, in order to avoid being poisoned by our own breath and that of others.

The removal of foul air and the introduction of that which is pure is called *ventilation*. Every room in which human beings are expected to live, ought to have some means of ventilation.

Has experience shown this to be true?—Our chemistry teaches us these facts, but chemistry is not left to do this alone. It is aided by some of the most awful experiences. Read:

Sometime more than a hundred years ago it happened that, in Calcutta, one hundred and forty-six persons were shut up for a night in a small room called the Black Hole. At dawn of day only twenty-three remained alive.

The passengers on board a ship were all crowded into the cabin, one stormy night. One hundred and fifty went in, but only eighty came out alive.

Examples of less painful kind are much more common. A

school-room is unventilated; the pupils become listless and dull from the influence of bad air. A church or hall is not ventilated, and a large audience becomes languid and sleepy. A bed-room has its door and windows tightly shut; the sleeper awakes in the morning unrested and with headache.

These are the effects of breathing air which has already been breathed before. Every boy and girl should know this fact and remember it.

How may a room be ventilated?—Two openings ought to be provided in every inhabited room. One of these should be near the top, the other near the bottom.

Out of one of these openings, foul air may escape; fresh air may come into the room through the other.

If the builder of the house has not made openings for this purpose, then the windows and doors may be used. A window let down a little from the top, and raised a little from the bottom, gives two openings which will answer the purpose.

Shall this be done at night?—It should be done both night and day. The fear of "night air," which is very common, is very groundless. One who understands such things says: "An open window, most nights in the year, can hurt no one. In great cities, night air is the best and purest to be had in twenty-four hours." Let us have the pure air in our sleeping-rooms as well as in our parlors.

There need be no current of air strong enough to be felt. Let the openings be made so as to avoid making such a current, or "draught," as it is usually called.

In mansions, churches and capitols there is some special means of ventilation almost always provided. We will not try to explain these contrivances now.

Do plants breathe?—Plants are living things and the air is their "breath of life." They take air into themselves and throw it back into the atmosphere again. This is a kind of respiration. It is not done just as animals do it. It is in-

deed a very different action from the breathing of an animal. The plant is built on a different plan from that of an animal, and so its respiration must be done in a different way.

In what part of the plant does the action occur?—It takes place in the leaves. The leaves are curiously made, so that they may do it. Look at one with a good microscope and we can see that its surface is not as smooth and even as we had thought. All over it we behold little *pores*. What a multitude! A thousand in the small space of a square inch! But the number is as small as this only in some cases. In some other cases there are not less than one hundred and seventy thousand to the square inch!

Each one of these pores is a little mouth. Think of the immense number of mouths a large tree must have. Into some of these, portions of the air are all the day passing, while out of the rest it is being exhaled.

Into what pores does the air enter?—The little mouths on the *under side* of the leaf are the ones which are chiefly engaged in taking the air in, while from those on the *upper side* the gases are thrown out.

What part of the air is needed by plants?—It is the water-vapor and the carbonic dioxide of the air which the plant needs. It must have these substances, else it dies. The oxygen of the air is of no use to the plant, but water-vapor and carbonic dioxide are all the time being used up by it.

What change occurs in the carbonic dioxide while in the leaf?—While in the leaf the carbonic dioxide is decomposed. Its carbon stays to help build up the growing plant, but its oxygen is thrown out into the atmosphere.

Does this decomposition go on all the time?—While the sun shines this action goes on. In the dark it does not. At night carbonic dioxide comes out as it enters. The delicate sunbeam enables the leaf to break up this stable compound and take the carbon into its own substance.

Bread-Tree of Tahiti.

The *bread-tree* owes its name to its curious fruit, so valuable for food to the natives of Tahiti.

All trees are not bread-trees, yet the vegetation which ornaments the earth is at the same time the source of all the nourishment of its inhabitants. Substances useful in the arts are likewise obtained from trees ; so too, are some of the most terrible poisons.

Strychnine is the poisonous substance in the *deadly upas.*

The Deadly Upas.

Describe an easy experiment.—Take a splinter of wood; let it be about as large as a common match. Plunge one end of it down a considerable distance into the chimney of a lamp. The wood will be quickly scorched but not set on fire. It will be scorched because it is in a very hot place, but it cannot burn freely because the chimney is filled with the products of the combustion of the lamp-wick and gives too little oxygen to produce a flame.

What is the result?—If we examine the scorched stick after the experiment, we find that it is no longer wood. It is blackened to its centre; it is nothing now, but coal.

What does this experiment teach us?—Now coal is chiefly carbon, and this carbon must have been in the stick before it was scorched. The heat drives some things away into the air; we see them going off as smoke, but it has left the carbon. The experiment thus teaches that *carbon is a constituent of wood.*

What are its other constituents?—To find out what elements, besides carbon, are in the wood is more difficult. Indeed we need not now puzzle ourselves with the experiments by which chemists have determined what they are. The analysis has been made many times, and it is easy to remember the results. Besides carbon, as the experiments have proved, the great bulk of wood consists of *hydrogen* and *oxygen.*

Is all wood made of these three elements?—All kinds of wood are alike in this respect. Carbon, hydrogen and oxygen are the chief constituents of all, no matter how unlike in appearance the different varieties of wood may be.

What besides wood consists of these three elements?—These elements are the constituents, not only of wood, but also of *every kind of vegetable matter.* Every blade of grass, every stalk of grain, every leaf and flower consists chiefly of carbon, hydrogen and oxygen!

Are these the only elements in plants?—Plants do indeed contain other elements than these. *Nitrogen* is found

in them ; in small quantities to be sure, but it must not be forgotten, because it is one of the most important elements in the vegetable food of animals.

Besides nitrogen there are several other elements in minute quantities which with carbon, hydrogen and oxygen enter into the composition of plants.

How large a part of the plant consists of carbon, hydrogen, oxygen and nitrogen?—When wood or any other vegetable matter is burned these four elements disappear and nothing but a little ash remains ; but this ash contains all the other elements of the substance burned. How small the quantity! It seldom amounts to one tenth of the whole. In every 100 pounds of vegetable matter, from 90 to 97 pounds are made up of carbon, hydrogen, oxygen and nitrogen!

We have already learned many things about hydrogen, oxygen and nitrogen, but it is now time to know more than we have yet learned about the other important element of plants.

CARBON.

Explain how carbon comes to be in plants.—Carbonic dioxide is one of the most important substances in the food of plants. But the oxygen of this substance is of no use to them ; it gets enough of that from other sources ; it is the carbon which is useful. Now every leaf of a growing plant is drinking in the carbonic dioxide of the air which passes over it. This we learn when studying the subject of respiration. While in the leaf this substance is decomposed ; its oxygen is exhaled but its carbon remains to enter into combination as a part of the body of the plant.

How is it obtained in the form of charcoal?—This carbon, which the plant has taken from the atmosphere, and

also the little which it may have taken up through its roots, is obtained without much difficulty for use in the arts, and we are acquainted with it under the name of charcoal.

Fig. 37.

The charcoal maker piles up his sticks of wood in the form of a mound (Fig. 37) and covers the whole with dirt and turf. He leaves a few small holes for a little air to enter the pile at the bottom and another at the top for the smoke to escape, and in this way a half smothered burning (Fig. 38) is kept up for a long time.

Now what change occurs? A very simple one. The wood is decomposed. Its gaseous constituents are driven away by the heat, but its solid carbon is left behind. Not all of it, to be sure, for a little of it unites with oxygen and flies away as carbonic dioxide. But that which is lost in this way is very little compared with the charcoal left.

What change in the appearance of the wood?—In appearance the wood only seems to have changed in color. It is black. Every part alike, no matter what may have been its color before, is black.

In other things it looks like the wood which gave it to us. There is the bark with all its knotty roughness. There are the annual rings of wood, inside the bark, to be plainly counted still, and, if we look through a microscope, there are the delicate cells, which the microscope could have shown us in the wood before it was burned. Let us lift it and it is easy to feel that the wood has lost much of its weight, but really it is not easy to see that it has lost much of its size ; the stick of charcoal is very nearly as large as the stick of wood before burning.

Why does charcoal show the same form as the wood?—All this obstinate resistance to any apparent change, but those of color and weight, is due to the fact that *carbon*

Fig. 38.

cannot be melted. The most powerful heat of the furnace cannot even soften carbon. There is no heat known that is strong enough to melt it. Whatever else is present in the wood can be driven away by heat, but the carbon cannot be moved. It stays just where it was, in every part, and so the delicate cell walls of the wood do not run together as they would need to do if they were made of a substance that could be melted. In spite of the fire every part of the wood retains its shape.

The property which prevents a substance from melting is called *infusibility*. Carbon is *infusible*.

Can water or other liquids affect carbon?—It is as careless about the action of liquids as it is about that of fire. Let us plunge a piece of charcoal into water. Years afterward, if left so long, the coal will be found to be as perfect as ever. Let us put it into more corrosive liquids, will it waste away? Not in the least degree. Liquids cannot attack it. Carbon is *insoluble.*

How does charcoal act upon gases?—Charcoal is very porous and it has a curious power of filling all its little cells with gases. Let a piece of freshly burned charcoal be sunk into a vessel of oxygen gas and it will at once begin to suck this gas into every pore, and will not stop until a large quantity is absorbed. A little block, one cubic inch in bulk, may be able to absorbe as many as nine cubic inches of oxygen—a quantity nine times as large as itself. Is this at all surprising? What, then, shall we say to the more wonderful fact that the cubic inch of charcoal is able to absorb about *ninety* cubic inches of ammonia gas and hold it bound, a prisoner in its cells!

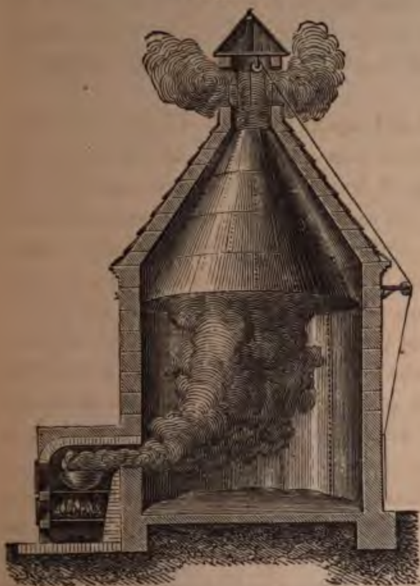
Is this power of charcoal of any use in the arts?—This remarkable power of charcoal makes it very useful in hospitals and other places where offensive odors are to be found. It will absorb the bad gases and thus purify the air.

Even animal substances, when decaying, lose their power to offend us by their odor, if covered with a layer of good charcoal. The decay will go on but the odor will be lost.

In what forms besides charcoal is carbon common?—Charcoal is only one of the many forms of carbon. No other element wears so many faces. Among those most nearly like charcoal we may mention now the *hard coal,* which is taken from mines for fuel; *coke,* the black and porous solid left in the retorts of gas-works; *bone-black,* obtained by heating bones in close vessels; *soot,* to be found in chimneys, and *lamp-black,* so much used in painting. All these would be

very interesting to study, had we time to do it, but only one of them, lamp-black, shall stop us for a moment now.

Fig. 39.



How is lamp-black made? In a simple way. Some pitch or tar is put into an iron pot (Fig. 39) and caused to boil. A dense black smoke rises from it, and is carried over into a large chamber. The blackness of these fumes is due to multitudes of fine particles of carbon. These particles collect on the inside of this chamber and may be afterward taken out in large quantities as a fine black powder. This is lamp-black.

What is this fine carbon powder or lamp-black good for? For many purposes; but there is one use more interesting than the rest. Look at this word printed in heavy characters —***Lamp-black.*** How black its letters are! Why are they so? Because they are made of lamp-black. *Printing ink* is a mixture of lamp-black and oil. Every printed mark upon this page is a thin layer of carbon clinging tightly to the paper. Never more let us despise this grimy dust. No other substance could so well fill the high office of preserving truth, upon the printed page, as lamp-black, because no other substance is so durable as carbon.

All these forms of carbon have very much the same proper-

ties, but there are other forms so unlike these that one can scarcely believe them to be carbon at all.

What is another form of carbon?—The *diamond*, most brilliant of gems, is nothing but carbon. It is crystallized carbon. Dull, black charcoal, very common and very cheap, and the beautiful diamond, most costly of precious gems, are only two different forms of the same element.

The diamond is the hardest known substance. It cannot be cut or even scratched by any other. Very small and otherwise useless diamonds are set in the end of a proper handle and are commonly used for cutting glass.

There are two principal forms of this most elegant jewel. They are called the *brilliant* and the *rose*. The first of these is regarded as the finest. Its shape is well shown in Fig. 40.

Fig. 40.

Look at the gem sidewise and it appears as seen in the upper part of the picture; look at the top of it and it appears as seen in the lower part. The form of the *rose* is seen in Fig. 41; a side view above and a top view below.

What other form of carbon is important?—Another kind of carbon is known under the common name of "*black-lead*" and is very familiar to us in its most useful form, the lead of our lead-pencils. This name does not belong to it properly, for it is not lead. It has no properties like those of lead ex-

Fig. 41.

cept that which allows it to leave marks upon paper. It is called, sometimes, *plumbago*; but the name which chemists give it is *graphite.*

Graphite is found in the earth. It is as black as coal, but it has a dull shining appearance which coal has not.

It is among the softest minerals to be found, and as perfectly opaque as can be. How much unlike the hard and transparent diamond in these respects!

In what things are coal, diamond and graphite alike?—All three of these forms of carbon are alike in some respects. No fire can melt them. No liquid can dissolve them, if we except melted iron, which seems to dissolve a little carbon. They cannot be changed by exposure to the atmosphere; they suffer no decay, no rust. But let them be heated hot enough, where oxygen is present, and they will burn.

What is the result of their combustion?—We have proved by experiment that when charcoal burns *carbonic dioxide* is produced. By heating the diamond to a white heat, in oxygen gas, it will be consumed, *carbonic dioxide* being the new substance found in its place. Graphite has also been burned, and the same substance, *carbonic dioxide*, produced by its combustion.

What does this prove?—This proves that the grimy coal, and the hard sparkling diamond, and the soft dull graphite, are really one and the same substance. For, do we not know that, whenever carbonic dioxide is formed oxy-

gen and carbon have combined to form it? Now what do we find? We find oxygen taking charcoal in one case, and diamond in another case, and graphite in another case, forming carbonic dioxide every time. Hence charcoal, diamond and graphite are all the same element—carbon.

How this element has come to be in such wonderfully different forms, we cannot tell. No chemist can change charcoal into diamond, nor can any one tell us how it has been done in the great laboratory of nature.

THE GROWTH OF PLANTS.

Describe an experiment with a bean?—Take a common bean and put it into water where it may stand in a warm place. After a day or two take it from its bath and with a penknife blade carefully remove its thin outer covering. Now notice; the bean is made up of two separate halves, and a little stem, short and plump, curled up at one end of them.

Put the knife blade between the two halves of the bean at the end opposite the little stem and gently press them apart. They separate freely, except at the stem; to this they are both joined. Look between the two parts, just above the stem. What pretty little thing is there? Two minute, delicate, but perfect white leaflets.

We see then that in a common white hard bean there is a stem and there are leaves. It is a little plant rolled up and dried.

What happens if the bean is planted?—Let a bean be planted and it is moistened by rain and warmed by the sunshine. Its tender covering soon bursts. Its tiny stem grows larger and longer. Its two halves are pushed up into the air, changing color as they go, until they come out in the form of two thick oval *green leaves* while the tiny leaflets between are much larger than before, and also green.

What more may be noticed?—Day by day the stem grows longer and the number of leaves increases. Nor is this all. There is something going on which is out of sight. Take the soil carefully from around the young plant and we see that the stem is pushing its way down into the ground, and that little branches are growing out from it in all directions. Both ways at once the plant is growing. Up into the air it pushes its stem and leaves; down into the ground it thrusts its roots.

What three distinct parts may be noticed in the plant?—The root, the stem and the leaves are the three parts of the young bean plant. Root, stem and leaves are three parts in every plant.

The *seed* of a plant is itself a little plant, which only needs the soil, the air, moisture and sunshine to develop into root and stem and leaves.

The *growth* of a plant is but the increase of the size and number of its *roots*, of the size and length of its *stem* and the number of its branches, and of the number and the size of its *leaves*.

An animal cannot grow unless it has food given to it. How could a body of any kind increase in size without receiving any new material? The growing plant needs food.

What elements are needed by a growing plant?—Now carbon, hydrogen and oxygen, with a little nitrogen, and very small quantities of a few other elements, make up every part of any plant. These the plant must get in some way, else it cannot flourish. If any of them are lacking, the plant suffers even if it does not die. The food of plants must contain all these elements.

In what substances does the plant find these elements?—Now the plant gets its carbon from *carbonic dioxide*. It gets its hydrogen and oxygen from *water*. It gets its nitrogen from *ammonia*. And as nine tenths of the weight of

plants is made up of carbon, hydrogen, oxygen and nitrogen it is easy to see that the three substances just named must be the food upon which plants must chiefly live.

But how can a plant take food?—Every plant has a multitude of mouths. There is one at the end of every little rootlet in the soil, and there are a host of them on the *under side* of every leaf. Each little root-mouth of a growing plant is taking in *liquid* food from the *soil*, and each little leaf-mouth is at the same time taking *gaseous* food from the *air*.

What is the liquid food?—The liquid, which enters the roots of a plant, is water in which many substances of the soil are dissolved. It contains compounds of ammonia from which the plant can get nitrogen, and it also furnishes the plant with those other elements which it needs in small quantities, those which make up the *ash* which is left when the plant is burned.

What is the gaseous food?—The gaseous food which enters the leaves of a plant is the carbonic dioxide and water-vapor of the air. From these gases the plant gets carbon, hydrogen and oxygen—the three most abundant elements needed in its growth.

Describe the circulation in the plant?—The liquid, which enters the roots of a plant from the soil, moves along through the roots and enters the stem. In the stem are a great many very small tubes, called sap-tubes, reaching upward through the stem and through the length of all the branches of the plant. Up through these tubes the fluid climbs. It spreads out into the branches. It enters every twig and every leaf-stalk, and finds its way into every part of every leaf. But having thus explored every portion of the leaves the sap begins a backward journey toward the soil. Not in the same channels through which it rose, but in another set of tubes it finds its way back. Thus up and down the stem, and through the branches, out and back again, the sap, in

ceaseless circulation, carries food to every part of the growing plant.

Is the character of the sap changed in this journey? —If taken from the lower part of the stem the sap is thin; farther up it is thicker, and on its way down it is still more dense. This change in the density of the sap shows that new substances are being made in it.

The food of plants must be *decomposed* before its carbon, hydrogen, oxygen and other elements can nourish them. These elements combine again in very different ways, and we shall soon see what common and yet what curious new substances they form to become parts of a growing plant.

With what substance shall we begin the descriptions?—With cellulose, because it is the most abundant. It is sometimes called woody fibre. When pure it is made up of nothing but carbon, hydrogen and oxygen.

How may we obtain woody fibre?—Let a piece of wood, or some flax, or straw, be bruised and soaked until nothing more can be washed away. Woody fibre will remain.

What are some of its properties?—It would then appear to be a mass of white fibres. It has no taste. Water cannot dissolve it; indeed if the fibre is pure it will not dissolve in alcohol nor in the strongest lye.

In what parts of the plant is it found?—It is found in every part of the plant. The trunk of a tree consists of slender fibres of this substance, which, when young, are tubes for the sap to flow in. It exists in the straw or stalks of grain; in the skin of seeds and in the cores and stems of fruit. The bran of corn and wheat, the partitions in an orange, and the delicate framework of a leaf, which you can see by holding a leaf up so that the light may shine through it, are made almost wholly of woody fibre.

What are among the purest natural forms?—Cotton and linen are the purest natural forms of this substance.

Cotton consists of little hollow white hairs which grow around the seeds of the cotton plant. Linen is the inner bark of the flax-plant ; indeed its most common name is flax, and it is generally called linen only after it is spun into thread or woven into cloth.

We cannot afford to leave this subject before we have noticed the wonderful fact that woody fibre can easily be made *explosive*; more terribly explosive than gunpowder.

Describe the experiment.—Mix an ounce of strong sulphuric acid with half an ounce of strong nitric acid. After the mixture is cooled, take small pieces of clean cotton wool and press them one after another into it. In about fifteen minutes lift the cotton from the acid and wash it in water until every trace of the acid is gone. Then spread the cotton out upon paper and let it dry in a warm and airy place.

Almost no change at all can be seen in the cotton after such treatment. It is still white, perhaps a little harsher to the touch and somewhat brittle.

What remarkable properties has it ?—Touch it with a red hot wire or a lighted match ; instantly a flash occurs and the cotton is gone! There is no smoke, no smell, and there is nothing left behind. It is as *combustible* as the gas we light our houses with.

Put a small piece of this curious stuff upon an anvil and strike it smartly with a hammer ; a violent explosion instantly occurs. It is more *explosive* than gunpowder.

What is this substance called ?—It is called *gun-cotton.* It is a dangerous thing to use in guns ; its explosion is so sudden and violent that it is apt to burst them. Its explosive force is three or four times greater than that of common gunpowder.

What is collodion ?—Gun-cotton is very soluble in ether. It forms a sirupy liquid called *collodion.* Let this solution be spread over any surface exposed to the air, and the ether quickly evaporates, leaving the cotton behind in the form of

a thin film. On this account it can be used instead of court-plaster. But its most extensive use is in the art of photography.

Thus a large part of the carbon, hydrogen and oxygen of the food of a growing plant is changed into *cellulose.* Another portion of these same elements is made into *starch.*

How may we obtain starch ?—Rasp somé potatoes on a grater ; put this pulp into a linen bag ; wet it thoroughly and then violently kneed, and squeeze it. A whitish fluid will be obtained. Let this fluid stand at rest for some hours, and you will then find that it has become clear ; the white substance having settled upon the bottom of the dish. Now this white sediment is *starch.* Pour off the water, and then pour on some more that is fresh, and let the starch settle again. Do this several times, and then dry the white powder in a warm place not too hot.

What are some properties of starch ?—When pure, starch is a snow-white powder. It is made up of little grains too small to be seen without a microscope. In some kinds it would take no less than *three thousand* of these little granules to make a row an inch in length! They are not always so small as this. Those of the potato are much larger than those of wheat or rice.

These starch grains are not of the same shape in different plants. In potato starch they are egg-shaped ; in wheat starch they have a shape much like that of a spectacle glass, thick in the centre and thin around the edges, while in rice they are angular.

In what part of the plant is starch found ?—Starch is very abundant in seeds and grains, such as corn and wheat and rice. It is found also in the pith and in the bark of many trees. Such roots as potatoes and turnips contain a great deal of it. All vegetable bodies that are used for food abound in starch. Indeed starch is itself a useful food.

Mention kinds of starch used for food.—*Corn starch* is very common ; it is made from Indian corn.

Tapioca is starch from the roots of a plant that grows in tropical countries.

Sago is starch taken from the pith of some species of palm-tree.

In what respect is starch like cellulose?—Cellulose and starch seem to be two very different things, and so they are in almost all their properties. But in one thing the two are alike ; they are both made up of carbon, hydrogen and oxygen ; and, what the chemist finds more curious still, is that they contain these elements in *exactly the same proportion.* Since they are made of exactly the same things and in exactly the same proportion we are a little perplexed to know why they should themselves be so unlike.

Thus cellulose and starch are two of the substances which a growing plant makes out of the carbon, hydrogen and oxygen which they get in their food ; *sugar* is another.

In what plants is sugar found?—Sugar is found in all plants. In some it occurs in small quantities ; in others it is very abundant. The maple tree, the sugar cane, the beet, Indian corn, grapes, plums and cherries contain it in large quantities.

In what condition is it found in them?—It is always *in solution* in the plant. It is in the sap of the *maple*, and in the juices of the *cane* and of *fruits*. In this respect sugar is very different from starch and cellulose ; they are always solids in the plant.

What are two important kinds of sugar?—Cane sugar and grape sugar are the two most important kinds. All our table sugar is cane sugar. Grape sugar is not so useful and common, but we have all seen enough of it to know what it is, for the white and sweet granules so abundant on the sur-

face of raisins, are grape sugar. Moreover the sweetness of honey is due to it.

Mention some differences in the two.—Cold water will dissolve cane sugar in much greater quantity than it will grape sugar. When the strong solution of cane sugar is allowed to stand quietly its water evaporates and the sugar is left in the form of crystals, known as "*rock candy*," but grape sugar will not separate in the form of crystals.

Both are composed of carbon, hydrogen and oxygen, but the grape sugar has a larger proportion of hydrogen and oxygen than the other.

From what is the sugar of commerce obtained?—The juice of the *sugar cane* furnishes nearly all of the enormous quantity of sugar found in the market. We must not forget the *maple tree*, which in our own country yields the delicious maple sugar; nor the *beet*, which in Europe is the source of sugar; but the quantity obtained from these is very small compared with that from the sugar cane.

How is it made?—The cane is bruised and pressed to make it give up its juice.

The juice is then treated to a small quantity of slaked lime and heated almost to its boiling point. By this means it is purified from some things which would cause the sugar to spoil quickly if they were not taken away.

The juice is next heated in large open pans. Its water goes off as steam and the sugar stays behind in the form of a thick sirup.

The sirup is allowed to cool, when the sugar separates in the form of small grains.

The granular sugar thus obtained is put into casks, having holes in them to allow the sugar to drain.

The sugar thus made is *raw* or *brown sugar*.

What is molasses?—The liquid drained off in making brown sugar is known as molasses.

How is sugar refined?—The brown sugar is dissolved

in water which contains a little lime, and a small quantity of *bullock's blood* is added; the mixture is then heated. Many impurities rise to the surface and are skimmed off.

The liquid is next strained through cotton bags; it becomes clear but it is still dark colored, and needs to be whitened.

The dark liquid is then passed through cylinders containing charcoal by which the color is taken away.

The bright colorless fluid is then "boiled down" to a sirup. The sirup is put into cone-shaped molds and allowed to cool and crystallize.

The white solid thus formed is *loaf sugar.*

Thus cellulose, starch and sugar are three very important compounds, which the plant manufactures from the carbon, hydrogen and oxygen of its food. Besides these there are a great many others.

Name some other substances which the plant makes from its food?—There are gums of many kinds; they flow out of the pores in the bark of some kinds of trees. Who has not seen *gum drops* on the trunks of the plum trees and the cherry trees? *Gum arabic* exudes from some species of acacia.

Name other bodies made by plants?—There are various kinds of oil manufactured by the plant from its food. Different plants make different kinds of oil. The flax plant makes *linseed oil*, which is obtained from its seeds. The castor oil plant makes *castor oil*, so useful in medicine.

What else is made in the plant?—Then there are the substances which give to plants their peculiar odors and which the chemist compels them to yield for use in making perfumes. The rich fragrance of the rose and the violet are due to substances made in these flowers out of the elements of their food.

Mention one thing more into which a part of the food of plants is changed.—The *coloring matters* of plants

are made in the plants, out of the material furnished by their food. Each flower decorates itself with its own peculiar color, but there is one color which is common to the stem and leaves of nearly all plants. The meadows and the forests alike are *green*.

The name of the substance to which we are indebted for the beautiful green color of our earth's carpet is *chlorophyl*. *Leaf-green* is an easier name to speak at first sight, but we can afford to make a little effort to remember the name of so important a substance as chlorophyl.

It is of a resinous nature, not soluble in water, fortunately, else the rains would bleach our forests. It is soluble in alcohol.

It does not occur in large quantities. A very little is able to color a great surface of leaves. Berzelius, a very eminent chemist, thought that in the leaves of a large tree there might not be more than *one hundred grains* by weight of chlorophyl!

Are there any other things made in plants?—The substances already named are a few of the most important ones which plants produce to build their growing bodies. There are a multitude of others which we cannot even mention now. The strangest and most puzzling fact about it is that all this host of different things is made out of so few elements. Carbon, hydrogen, oxygen with a little nitrogen, and very small quantities of very few other elements furnished by the food of plants, compose them all.

THE DECAY OF PLANTS.

While a plant is living, air and moisture only help it grow, but when dead the same substances break it up and reduce it to the form of earth. Now what are the chemical changes which take place when wood decays? To answer this question let us cause some wood to decay in such a way that we can study the action and test the results.

Describe an experiment.—Suppose we put some fine saw-dust into a bottle which may be corked air tight. Let us thoroughly moisten the saw-dust first and then close the bottle. No change will be seen at once; indeed we must wait patiently many days; but at length if we keep the bottle warm, we shall find that the wood is partly decayed.

Next let us open the bottle and examine the air inside. A little lime water tells us that it contains carbonic dioxide. This then is one of the things produced in the decay of the wood. We can easily explain it: the wood has given up a part of its carbon, and the air, above it, has given up a part of its oxygen, and these two have combined to make the carbonic dioxide.

What else occurs?—This experiment cannot tell us of some other changes that take place in the decay, but the fact is that water is another substance produced. The wood gives up a part of its hydrogen, and the air gives up a part of its oxygen, and these two combine to form water.

Here then we have the most important chemical changes in the decay of wood.

Briefly explain the process of decay.—The wood is slowly decomposed. A part of its carbon takes oxygen and forms carbonic dioxide. A part of its hydrogen takes oxygen and forms water. These substances escape into the air. The rest of the carbon and hydrogen of the wood remains in combination with oxygen and stays behind as a loose, moist and dark colored solid.

Are these things true when other vegetable matter decays?—When any kind of vegetable matter decays, the same changes occur. That which grows in one season decays the next. Water and carbonic dioxide are added to the atmosphere while a layer of loose and dark colored mold is left to enrich the soil.

How does this action resemble combustion?—This process is very much like the more brilliant process of com-

bustion. In the first place, the same elements, carbon and hydrogen, from wood or other fuel, take part in both actions. In the second place, oxygen is used in both. In the third place, water and carbonic dioxide are produced by both. The chemical actions seem to be the same.

The chief difference between decay and combustion is in the rapidity of the actions. A piece of wood that will be burned in a few seconds will need months to decay. Decay is a kind of slow combustion.

To such chemical actions we owe the disappearance of every yearly growth of the grasses, the weeds and the flowers. All dead vegetable matter exposed to the atmosphere must suffer such decay. But sometimes wood and other vegetable matter is buried in the earth where the air cannot get to it. Sometimes, too, it is washed down into the sea and is buried under the mud at the bottom, so that the atmosphere cannot reach it. What then? Will it decay? It will last much longer than if the air could reach it, but it cannot finally escape.

Can decay away from air be the same as in its presence?—In the decay of bodies in the air it is the oxygen of the atmosphere which attacks them and breaks them up into water and carbonic dioxide. Away from the air, no oxygen would be furnished, and we ought not to expect that the same action would take place. Is it not easy to see that the decay of wood buried away from the air must be quite a different thing from the decay which takes place in its presence?

In what does it consist?—Decay under such circumstances consists chiefly in a change among the elements of the wood itself. These elements are carbon, hydrogen and oxygen. They are arranged in a certain way in the perfect mood, but when shut away from air, they begin to slowly change the order in which they find themselves. The oxygen takes some of the carbon and together they escape as carbonic

dioxide. The hydrogen also combines with a part of the carbon. They form a great variety of compounds, some of which are gaseous and escape, while others are liquid in form, and remain with the rest of the solid carbon.

Give an example of such a process going on at the present day.—Such a process is going on now at the bottom of marshes. The plants to be found in such wet places often grow luxuriantly in the summer, but before the next season comes their dead bodies have fallen down upon the mud below. Here their slow decay goes on.

What substance is thus formed?—*Peat* is one of the substances formed in this way. The name is given to vegetable matter in which the decay is not half complete. The swampy places of Ireland are the most noted peat-beds in the world; it is said that one tenth the surface of that island is covered with peat.

This substance is a very valuable fuel. Vast quantities are taken from the beds, cut into blocks and dried in the sun for this purpose.

What other substance is thus formed?—*Bituminous coal* has been produced from vegetation very much in the same way. Why then, is its composition different from peat? Simply because the decay has gone on farther. Its oxygen is all gone. The gases of the decomposition have all escaped, and only the carbon with the liquid compounds of carbon and hydrogen are left.

But there is another striking difference between bituminous coal and peat; coal is very compact, peat is not. Why this difference? The pressure of all the rock and soil and water above it, could not fail to crowd the soft decaying vegetable matter more and more closely together, and this seems to be a good reason why coal is harder than peat.

What is another product of this slow decay?—*Anthracite coal* is finally produced by this slow decomposition in the earth. The action, we suppose, has not stopped when

bituminous coal is made. The liquid compounds of hydrogen and carbon have slowly escaped until all are gone. Nothing but the solid carbon is left.

What could have caused this change? Well, here are two facts which we *know*: First, the earth is hotter in the interior than it is at the surface. Second, let bituminous coal be heated, away from air, and its liquid compounds will be driven off. Now these facts lead us to say that bituminous coal, buried deeply in the earth, away from air, will have its liquid compounds slowly driven off by heat until only its carbon is left. And then if we remember that the heavy mass of rocks above it must have pressed with enormous weight upon this carbon to harden it, we understand how anthracite coal has been formed in the earth.

When were the coal beds formed?—The coal beds in the earth were made so long ago that we cannot measure the time in years. It was before the first man was created; how long before no one can tell. It was long before the kinds of trees and plants, now so common, began to grow upon the earth. It is called the *carboniferous age*, and several other *ages* have passed since then.

What other substance has been formed by the decay of vegetable matter in the earth?—Oily liquids, called *mineral oil* or *petroleum*, have been also given off by decaying vegetable bodies deeply buried in the earth. They are the liquid compounds of hydrogen and carbon so often spoken of already. Petroleum is not a single substance, but it is a mixture of many kinds of liquid, all alike, however, in being composed of the same two elements.

What is naphtha?—By gently heating the crude petroleum, that comes from the earth, and then cooling the vapors that rise from it, a very limpid and colorless liquid is obtained. This is *naphtha*. Sometimes naphtha is found by itself in the earth. It is the purest form of the native rock-oil.

Naphtha is very combustible. It is always ready to pass away as vapor, when left in open vessels, and the mixture of its vapor with air is terribly explosive.

What else may be obtained by heating petroleum? —A great variety of such hydro-carbon oils may be obtained by heating petroleum to different temperatures. One among them is *kerosene*, so commonly used in lamps. The vapor of this substance mixed with air is as explosive as gunpowder. When well made, however, kerosene will not give off its explosive vapor by the heat which it is likely to get in a well-made lamp. It needs a higher heat, and on this account it can be safely used. But, unfortunately, the fluid, as found in the market, is not always well prepared. It often contains oils which give explosive vapors at low temperatures. Sometimes even naphtha itself is one of the constituents. The use of such burning fluids is extremely dangerous.

What more may be obtained by distilling petroleum? —When all these very volatile oils have been driven away by heat, from the crude petroleum, there is left a dark colored solid substance called *asphaltum*. This substance is quite hard at low temperatures, but when warmed it is soft, and if it is heated to a high temperature in air will burn with a smoky flame.

But we need not distill petroleum to get asphaltum; nature has done this work on a large scale in some places, so that this "*mineral pitch*" is a very abundant natural product. Think, for example, of the Great Pitch Lake, on one of the islands of the West Indies. It is three miles in circumference and its depth is not known. The shore of the Dead Sea is another noted locality where asphaltum is found, but we will not stop to notice other wonderful deposits of this substance.

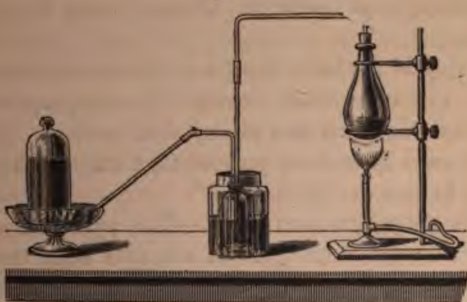
THE EFFECT OF HEAT ON WOOD.

When wood is heated to high temperature in the open air it burns; is this combustion the effect of heat? Truly, it

could not occur without the heat, but then, combustion is an action between the wood and oxygen gas, so that it is not so much the effect of heat, as it is of hot oxygen. If we would know what effect *heat* may produce, we must let *heat* act *alone* upon the wood. We must heat the wood in a place where there is no air. Let us see how this can be done. The picture represents the process.

Describe the apparatus?—Splinters of some hard wood,

Fig. 42.



we will say that it is beech, are put into a flask This flask is shut air-tight with a cork. A bent tube reaches from the flask over to a bottle which stands in a larger vessel containing cold water. From this bottle there is another bent tube reaching over to a receiver standing in a cistern of water.

Describe the experiment.—Heat is applied to the flask. The wood very soon begins to turn black and gases begin to flow out through the bent tube. They pass into the bottle and from there they may go over into the receiver. But all do not go over; some are condensed by the cold and become liquid in the bottle. After a time the flow of gases stops and the work is done. What are the results?

What substances are obtained?—In the flask nothing but a coal-black mass is left. Indeed it is nothing but *charcoal*.

In the bottle a dark colored *liquid* is collected, while in the receiver we find a quantity of *gas*.

We are acquainted with charcoal, but what are these liquid and gaseous substances?

Describe the liquid products.—There seem to be two liquid products caught in the bottle. One of these is a very dark colored resinous substance which is called *wood-tar*. The other is a dark brown liquid with a sour and smoky taste. It is *pyroligneous acid*. Both of these substances are valuable.

For what is tar used?—Tar is extensively used in ship building. For this and other more familiar purposes a great quantitiy of this black and pitchy stuff is used. It is made on a large scale by heating pine wood, the resinous pine more commonly known as "pitch pine."

What is pyroligneous acid?—The pyroligneous acid is a mixture of several things. It owes its sour taste to the *vinegar*, or, as the chemist calls it, the *acetic acid* in it. Its smoky taste is due to a curious substance called *creosote*. Besides these two liquids this acid contains another, a very limpid liquid which is colorless and combustible, known as *wood-spirit*.

Are these substances useful?—The acetic acid from wood is very valuable because it can be used to make compounds needed in the art of coloring cloth.

Creosote has the most wonderful power to preserve bodies from decaying. Examples .of its action are very common. Meat is often *smoked* in order to preserve it, but unless the smoke contains creosote the operation is useless. Wood-smoke does contain it, and the "curing" of tongues and hams and other meats, by smoke, is due to creosote. It is a constituent of wood-tar as well as of pyroligneous acid; and

when bituminous coal is heated in close vessels, the coal-tar obtained also contains creosote.

Wood-spirit burns with a very hot flame, and chemists use it sometimes, as a source of heat in their lamps. It can dissolve resins very powerfully, and it is used for this purpose in making varnish. We call it wood-spirit, and this is well; but in chemistry it has been given the more dignified title of *methylic alcohol*.

These three compounds are important substances. Very many other things can be obtained by carefully distilling the *liquid* products of heating wood in air-tight vessels, but we will not stop to study them now.

What are the gases obtained in the experiment?—The contents of the receiver (Fig. 42) is not a single gas; it is a mixture of several. We will name only the two which are the most important. One of these is *marsh gas;* the other is *olefiant gas*.

Where is marsh gas to be found in nature?—Marsh gas is rightly named, because it is abundant in marshy places. Have you never seen the water of ponds and quiet pools stirred by bubbles rising from the bottom? It is a very common thing in water standing over muddy bottoms. The bubbles are of marsh gas. They are set free by the decay of vegetable substances in the mud below. Look at the picture (page 102) and see how they may be caught in a bottle having a funnel in its neck.

Marsh gas flows from coal beds into the mines where the laborers are at work. The most awful effects are then sometimes produced by it. It is very combustible, and, more than this, when mixed with air it is terribly explosive. Fancy it flowing into a mine, mixing with the air all around the miners, and the mixture then touching the flame of the miner's lamp! The lamps and the lives of the miners would be extinguished at once by a terrible explosion. Alas! It is not all a fancy; such accidents have happened many times.

By what other names is marsh gas known?—By the miners, marsh gas is called *fire-damp*. Another common name for it is *light carburetted hydrogen*, but its real chemical name is *methylic hydride*.

Fig. 43.

What are some properties of olefiant gas?—Olefiant gas is much like marsh gas in some respects. For example, it is colorless, very ready to burn, and very explosive when mixed with air. Its flame is more brilliant than that of marsh gas; it gives a very white and beautiful light.

In what common substance are these two gases found?—By those who live in cities and large towns these two gases are in common use. *Illuminating gas* which lights their houses is a mixture of them. We do not mean that it contains nothing else, for there are small quantities of several other gases with them, but the value of illuminating gas is due to marsh gas and olefiant gas, and it would be better than it ever is, if it contained these two alone.

Is illuminating gas obtained from wood?—The illuminating gas for lighting cities and towns is not obtained by

heating wood ; to do so would make it too costly. The substance generally used is bituminous coal.

How is it obtained from coal?—If bituminous coal be heated just as the wood was heated in the experiment which we have studied, (Fig. 42) a large quantity of the mixture of gases is caught in the receiver. Indeed that experiment may help us to understand the operation as conducted on a large scale.

What is used instead of the flask?—Instead of the flask, in which the wood was heated, there are several long iron cylinders set in a furnace. Each one of these will hold as much as one hundred or one hundred and fifty pounds of coal.

When these cylinders have been filled with coal, they are shut air-tight, and the furnace fire is kindled. The intense heat soon changes the volatile parts of the coal to gas, and drives it out of the cylinders just as the lamp flame did with the wood in the experiment shown in figure.

What is used instead of the bottle?—Instead of the bottle in which the liquids were caught, (Fig. 42) there are several different things through which the impure gas must go. The most important of these are :

1st. A horizontal cylinder, quite large and partly full of water.

2nd. Several tall upright pipes so fixed that the gas must go up one and down another until all have been passed.

3rd. A chamber with shelves on which a large quantity of lime is placed.

Why are so many things needed?—All these things are needed to catch the liquid, and other impurities that come off with the gas from the heated coal. By the time the mixture has passed through them all, it is fit to be burned in the chandeliers, to give light to the people in their homes.

What is used instead of the receiver?—Instead of the glass receiver in which the gases were caught (Fig. 42,) there

is an immense sheet-iron tank placed bottom upward in a great water-cistern. From the lime chamber the gas goes through a pipe into this tank, and there it is kept until it is needed in the houses for light.

How is it taken to the houses?—There is a large pipe reaching from the inside of the great tank—the *gasometer*, as it is called, down under ground into the street. This pipe branches off into other streets and these branches give off other branches which lie under ground in other streets. Now the weight of the huge gasometer, presses the gas out into these pipes which run along under the streets of the city.

A branch pipe reaches from the street pipe into each house, and this gives off branches to the different rooms, and at the end of each of these there is a gas-burner or chandelier.

Is this gas like that obtained from wood in the experiment?—This illuminating gas, or coal gas, as it is often called, consists chiefly of *marsh gas* and *olefiant gas*, the same gases which are obtained by heating wood, as in the experiment described. Coal is used instead of wood because it is cheaper.

Are the liquid products like those obtained from wood in the experiment?—The liquid products obtained in the gas-works are very much like those obtained by heating wood. They are not exactly the same.

Mention one kind.—There is among them one kind which contains *ammonia*. These ammoniacal liquors are valuable; ammonia, or *hartshorn* as it is often called, is made from them.

Mention another kind.—Coal-tar is another substance obtained by heating coal in the work of gas-making. It is very much like wood-tar. Some very useful substances are obtained from it.

What can be obtained from coal-tar?—One of the most important is *carbolic acid*. We will not try now to explain *how* this and the other valuable things are obtained

from coal-tar; the higher text-book of chemistry (see p. 181) will tell you more about it than you are now prepared to understand. But it is easy to remember that from the dark and dirty looking coal-tar a *white solid* can be obtained, called carbolic acid; that it can be dissolved in such liquids as soda and potash, and that it is in great demand as one of the best things to destroy bad odors, to help in the cure of some diseases, and to assist in making colors for dying silk and woolen goods.

What is another useful substance obtained from coal-tar?—Coal-tar gives us another useful substance called *benzole*. This is a liquid as limpid and colorless as water. It is very combustible, and its vapor, mixed with air, is terribly explosive. It ought never to be used, though it sometimes is, as a burning fluid for lamps. It is very useful for taking oil stains from garments.

What substance can be made from benzole?—The chemist does not always stop when he has obtained benzole. He sometimes mixes some strong nitric acid with it and thus brings about a curious change. A new substance is thus made which has the odor of bitter almonds and which is useful in making perfumes and confectionery. This new substance is called *nitro-benzole*.

Into what may nitro-benzole be changed?—Nor does the chemist stop with nitro-benzole. By rather complex chemical actions which he knows how to produce, he changes the *nitro-benzole* into another curious liquid called *aniline*.

Aniline is a heavier liquid than water. It is itself *colorless*, but yet some of the richest colors ever seen can be made with it. Various beautiful shades of red, blue, yellow, and several other colors are made with aniline by the use of different chemicals. The beautiful *aniline colors*, so popular and so useful in the arts, are all made from the dark and offensive coal-tar.

Mention the several steps from coal-tar to aniline colors.—The coal-tar obtained in gas-works is made to furnish *benzole.*

The benzole is changed in *nitro-benzole* by the action of nitric acid.

The nitro-benzole is changed by the action of iron and acetic acid into *aniline.*

The colorless aniline is oxidized in different ways to produce the rich aniline colors for use in the arts.

Fig. 44.

What happens when a piece of marble is put into an acid?—Let some hydrochloric acid be put into a deep glass vessel, enough to cover the bottom an inch in depth, and then let some small pieces of marble be dropped into the liquid. A furious foaming at once begins; the marble wastes away gradually, and bubbles of a colorless gas escape in great numbers.

What is this colorless gas?—When the action is over let a lighted taper be put down into the glass vessel. The flame is instantly put out, and from this we infer that the vessel contains *carbonic dioxide.*

What does the experiment teach?—It is known that there is no carbonic dioxide in the hydrochloric acid, and

hence it must be that this gas came from the marble. We learn that carbonic dioxide is a constituent of marble.

What happens if marble be heated in a furnace?—Let a piece of marble be heated in a furnace made very hot and its character will be considerably changed. It will be whiter than before. It will be more easily powdered. But it will remain solid and be of the same size as before.

Is there any other change produced?—A change is made in the nature of the marble, by the heat. How can we tell this? Easily. Put the burnt marble on a plate and pour a little water upon it. At first nothing strange appears, but very socn the stone begins to swell and crack and crumble, while large volumes of steam rise into the air. (Fig. 44.) When all is over we find that the stone has crumbled to a fine white powder.

What is this powder?—This powder is called *slaked lime;* the stone, before it was slaked by the water, was *quicklime*, or simply *lime.*

When marble is intensely heated, it ceases to be marble; it is changed to lime.

What do we learn from this?—We thus learn that lime is a constituent of marble.

Of what two things does marble consist?—The experiment with the acid showed that marble contains *carbonic dioxide;* the heat of a furnace drives this gas away and shows the marble also contains *lime.* These two substances are the constituents of marble. Other things *may* be present in the stone, or they may not be; these two, however, *must* be, or the marble cannot exist.

Suppose other things are present in considerable quantities?—The marble is then of poor quality and if the other substances are in too large proportions, the stone is no longer worthy to be called marble; it is *limestone.*

Is limestone abundant?—This stone is one of the most

abundant substances in the earth. Over immense tracts of country the rock on which the soil rests is limestone.

Marble is the purest kind of limestone; it is the best example of what are called *calcareous rocks*—so called because lime is a chief constituent.

The *calcareous rocks* form one of the few large classes of rocks which make up the solid parts of the earth. Carbonic dioxide and lime are their chief constituents.

Of what is lime composed?—Lime is a compound of two elements. One of them is our familiar acquaintance—oxygen, but the other has been, up to this time, a total stranger to us; its name is *calcium.*

What are some properties of calcium?—Calcium is a *metal.* It is about as hard as gold. It has a shining, light yellow color, but soon tarnishes in air. It is very malleable; sheets of calcium may be made as thin as sheets of paper.

The yellowish shining calcium and the colorless gaseous oxygen, combine to form the dull white stony lime!

What then are the chief elements in marble?—Since lime consists of calcium and oxygen, and carbonic dioxide is composed of carbon and oxygen, we see that marble must consist of the three elements, *calcium*, *carbon* and *oxygen.* These three are the chief elements in the calcareous rocks.

Of what does sandstone consist?—Sandstone consists of grains of sand cemented firmly together. In the hard brown-stone used for building purposes the particles of sand are *very* firmly held together, but they are not always so. Sometimes they are held so feebly that the stone can be crushed by our fingers. These grains are in most respects the same as the "sands on the seashore."

But what are the grains of sand?—Grains of sand are made of what the chemist calls *silica.* There are enough of

other things with the silica to give the sand its yellow or brown color, but the quantity of these impurities is very small.

What are other forms of silica?—Flint is a kind of stone, very hard, sometimes white, sometimes grey, brown or black, but always a variety of silica.

In some places very fine, transparent, diamond shaped crystals are found in the rocks; they are called *rock crystal*. They consist of silica, almost pure.

The common name of these hard varieties of silica is *quartz*.

What are other varieties?—The beautiful *amethyst* is quartz crystal with a delicate purple color.

The precious *opal*, the *chrysoprase*, the *bloodstone*, are little else than silica.

Mention some other precious stones which are chiefly silica.—*Jasper* is a very fine-grained form of silica, colored generally red, but sometimes black.

The *agate* is a form of silica in which many tints of color are delicately arranged in stripes or bands.

When the colors are few and very regularly arranged the agate is called an *onyx*. When the color is uniform, and a pearly white, the stone is a *chalcedony*, but when red is called *carnelian*.

Notice here, that most of the "gems" and "precious stones" are different forms of silica. They reside in palaces, with the high-born and wealthy. Who would suppose that they could be such near relations of common country sand!

What name is given to rocks which contain silica?—Sandstone and other rocks in which there is much silica are called *silicious rocks*.

The silicious rocks are, like the calcareous rocks, one of the great classes of rocks of which the solid earth is made.

What is silica?—Silica is a compound of two elements. One of these we have found to be a constituent in almost

every substance we have studied thus far : it is oxygen. The other we have not yet even named: it is *silicon.*

What kind of a substance is silicon?—Silicon is in some respects like carbon. It is a dark colored powder usually, but then it may have two other forms a little like graphite and diamond.

Very much less is known about silicon than about carbon. It is, next to oxygen, the most abundant element in the world, but it is never found alone ; it is combined with oxygen, and the two do not like to be separated. Immense quantities of silicon are hidden in the sandstone rocks, so very common, yet very few persons who are not chemists have ever seen it.

What is slate?—Slate is a kind of rock which can be split into thin plates. The " slate " on which we write in school, and the " slate " used in roofing buildings are familiar examples.

Vast beds of this kind of rock are found in many parts of the world ; and great quantities are quarried for roofing, for side-walks in cities, and for other useful purposes.

Of what is slate rock composed?—One of the most important substances in this rock is silica ; there is another, the name of which will be new to you ; it is *alumina.* These are not the only substances in slate. Indeed there are a great many others in it, but these two are always present and are the most prominent constituents.

What name is given to rocks which contain much alumina?—Slates and other rocks in which there is much alumina are called *argillaceous rocks.*

The argillaceous rocks, like the calcareous and the silicious, are one of the great classes of rocks in the solid earth.

What is alumina?—Alumina is a compound of two elements. One of these is oxygen ; the other is *aluminum.*

What kind of a substance is aluminum?—Aluminum is a *metal.* In color it is a trifle more blue than silver. It is very light—not one quarter as heavy as silver, but like silver it does not easily tarnish in the air.

This metal is used for ornamental purposes in the arts to some extent. Light weights for delicate balances are also sometimes made of this substance.

Is aluminum abundant?—Next to oxygen and silicon this element is the most abundant in nature. It occurs not only in slate rocks; it is also found in clay. Not a particle of clay exists that does not contain a little aluminum. One would think that a thing so abundant might be easily obtained, but this metal is not. It is so firmly bound in with the oxygen and the silica, that the chemist is puzzled to know how to set it free.

Of what is granite composed?—If we look at a piece of granite very carefully we may see that it is made up of little crystalline particles. Some of these are white, or nearly so; others are of a yellowish color; while others still are little scales of a brownish hue.

The whitish grains are *quartz;* the yellowish ones are *feldspar,* and the little brownish scales are *mica.* Granite is made up of these three substances.

What are granitic rocks?—There are several kinds of rock which are very much like granite, yet not the same. These with granite are called *granitic rocks.* They are thought to be the oldest kinds of rocks in the earth.

What are the elements in these rocks?—The chemist has found that these rocks are chiefly composed of compounds of *silicon, aluminum, calcium* and *oxygen.*

These are not the only elements they contain; several others in smaller quantities are found in them.

What is potassium?—One of these other elements is potassium. It is not found alone, but it is combined with the inevitable oxygen.

Potassium is a *metal*, but is so different from the common metals that we must examine it before going further.

What are some of the curious properties of potassium?—Most metals are heavy bodies, but this one is *lighter than water*. Let a piece be dropped upon water and it will float, like cork, upon its surface.

Fig. 45.

Nor is this the only thing that will surprise one who drops potassium upon water; the metal will instantly take fire. Violet-colored flame will burst from it, while the melted globule will run about wildly over the water, wasting away all the time until, when nearly all gone, it will usually put a stop to the action by an explosion.

There is another curious thing about this metal. Most metals are very hard, but this one is as soft as wax.

For what substance has potassium a strong attraction?—Potassium has a strong attraction for oxygen; the two combine whenever they come together. This is why the metal takes fire on water; it seizes the oxygen and pulls it away from the hydrogen of the water and combines with it itself. When exposed to air it also combines with oxygen, and on this account its surface is never bright more than a minute after it is freshly cut.

What substance does this metal form with oxygen?—The new substance formed when potassium and oxygen combine is *potassa*; it is often called potash.

Potassa is one of the substances found with silica, alumina, and lime in the granitic rocks.

What is sodium?—Sodium is a metal very much like potassium. It is soft like wax; it will float on water, melt into a globule, and run briskly around over the surface of the liquid and waste away as potassium will do, because it has a strong attraction for the oxygen in the liquid.

What is soda?—The compound of sodium and oxygen is called *soda*. Soda is another of the substances found with silica, alumina, and lime in some of the granitic rocks.

What is magnesium?—Magnesium is a silver-white metal. It is heavier than those just described, but still we must regard it a very light metal; it is not quite twice as heavy as water, while iron, pieces of which we have so often lifted, and with whose weight we are more familiar, is more than seven times heavier than water.

Magnesium can be made into thin sheets, and it can be drawn into wire. In both these forms it is found in the market.

This metal is very *combustible*. Magnesium wire will burn with a most dazzling light when set on fire by bringing one end of it into a lamp-flame. The fire will run up the wire very rapidly, and great volumes of white smoke will be made.

What is magnesia?—This white substance just mentioned is magnesia; it is a compound of magnesium and oxygen. Magnesia is another of the substances found with silica, alumina, and lime in the granitic rocks.

We will not stop now to notice the very few other substances that exist in these rocks.

How many classes of rocks have we now studied?—We have noticed four classes of rocks, the *calcareous*, the *silicious*, the *argillaceous*, and the *granitic*.

These rocks make up the solid parts of the whole earth. If we remember the substances of which these four classes

are made, and what has been said of them, we know something about what seems to have been the most important materials of which the world is built.

What is soil?—Soil is the loose earth which rests upon the solid rocks. It is made of the same materials as the rocks themselves. Indeed soils have been made by the crumbling of rocks.

Fig. 46.

Is it difficult to see how solid rocks could be broken and ground to powder to form the soil? Look at this picture. It shows how the wild sea-waves have worn their way far into the solid rock of the coast against which they dash. What has become of the rock, worn out from under that

overhanging cliff? It has been washed away, and now lies upon the bottom of the sea. Some day, perhaps, the sea will leave its present bed; such things have happened in the past. What then? This powdered rock will be a part of the loose dry soil.

Water is forever wearing the rocks away; and the air, and heat, and cold, are helping it. The soil is little more than crumbled rock.

What substances do soils contain?—The same substances which compose the rocks must also be found in soils. Silica, alumina and lime are leading constituents, and we may name all those others which, as we have learned, are found in the different classes of rocks.

Do soils contain anything not obtained from the rocks?—But soils do not get all their substance from the rocks; some things are given to them by plants. The vegetation of one season decays the next, and the remains of it are left to enrich the soil.

Of what two parts do fertile soils consist?—One part of the soil is derived from rocks; one part from plants. We call the first the *mineral* part; we call the second the *organic* part.

Which is the larger part?—The mineral part of soils is by far the larger part. It is more than nine tenths of the whole. In a hundred pounds of soil there are from *three* to *ten* pounds only of organic matter.

What substances must a fertile soil contain?—We have seen that plants get a part of their food from the soil and a part from the air. Now a fertile soil is one on which plants can flourish; is it not clear that a fertile soil must contain all the substances that are found in that part of the food which plants must get from the ground?

What are these substances?—These substances are the ones that do not fly away when plants are burned; they compose the ash that is left behind.

What are their names? Here they are: Silica, lime, magnesia, potash, soda, oxide of iron, sulphuric acid, phosphoric acid.

All plants do not take exactly the same constituents, and these eight are not quite all that are sometimes found in them.

All these are to be found in rocks and soil. The last three on the list were not described when speaking of the rocks; it was because we can describe them better at another time. A fertile soil contains all these, and also a proper amount of organic matter—that is to say, from three to ten pounds in every hundred.

Having all these, is a soil necessarily fertile?—But all these things may be present in a soil, and in good proportions too, and yet the soil will not be a fertile one. How is this? The soil may be too wet; it may be too compact; too coarse or too cold. To be fertile a soil must have the right *chemical* composition; but this is not enough, it must be in the right *physical condition* also.

But we must not pursue this subject further now. It is well to stop just here, lest we find ourselves studying the science of agriculture instead of chemistry.

Fig. 47.

PRIESTLEY.

ELEMENTS.

What is an element?—An element is a substance that has never yet been separated into any other kinds of matter. (p. 29.)

Name the elements which we have noticed in our study thus far.—We found that *water* is made up of:

Oxygen,
Hydrogen.

In the study of *air* we added to the list:

Nitrogen.

In the study of plants we found besides these:

Carbon.

In studying the soil we found:

Silicon,
Aluminum,
Calcium,

Potassium,
Sodium,
Magnesium.

How many elements are known to exist?—By making experiments to learn the composition of bodies, such as air, water, earth, and a host of other things, chemists have found SIXTY-THREE elements. It is possible that there may be others, still hiding in some corner of the world which chemists have never looked into, but this is uncertain, and hence it is supposed that everything in the earth or around it is made of these 63 elements.

Are all these very common?—Only a few of these 63 elements are to be found in common things. We have learned the composition of air, water, earth and plants, and have described only ten elements in so doing. Had others been as common as these ten are, we should have described them also. There are a few others, however, which are very important, even if very much less abundant than the ten we have named. But when we have added these to the list it will not include more than *one third* of the 63. The remaining *two thirds* are very rare.

What are the names of those which it is important for us to add to our list?—To the list of ten already named as most abundant we will now add the following important elements:

Chlorine,	Zinc,
Bromine,	Tin,
Iodine,	Lead,
Sulphur,	Mercury,
Phosphorus,	Silver,
Arsenic,	Gold,
Iron,	Copper.

Let us next endeavor to become acquainted with these strangers.

CHLORINE.

About one hundred years ago —it was in 1774—a Swedish chemist by the name of Scheele was studying the action of hydrochloric acid on a black powder known as the "black oxide of manganese." To his surprise a heavy greenish gas was produced. This gas was *chlorine*; it had never been found before.

Fig. 48.

How can we obtain chlorine?—To obtain this gas we may use the apparatus shown in Fig. 48. We will put some of the manganic oxide—such as Scheele used—into a flask such as is shown at the right in the picture, and then close it with its cork. We will next pour some hydrochloric acid through the funnel-top tube into the flask, and then finally we will apply a gentle heat.

What now happens?—The acid gives up the chlorine which it contains. This gas passes over through the bent tube into the bottle with three necks. This bottle contains some water, and the *gas will be washed* by bubbling through it. Passing from this bottle it goes over through another bent tube into a tall jar holding some calcic chloride, by which the *gas will be dried.* The dry pure chlorine will then go over into the receiver. You see that the tube will carry the gas down to the bottom of this receiver and the chlorine will fill the vessel gradually from the bottom without mixing with the air.

What are some of its physical properties?—*Chlorine is a yellowish-green gas.* Sir Humphrey Davy gave it the name it bears on this account. He took the Greek word *chloros*, which means *green*, and made the name chlorine from it.

Chlorine has a very strong and suffocating odor. Whenever it is used for experiments a little is likely to escape into the room, and even if the quantity be very small, it will give its own peculiar odor to all the air in the room. It is very difficult to tell another how this gas smells; its odor is so peculiar that it must be received in order to be known; but once received it will never be forgotten.

Chlorine is a very heavy gas. This is seen in the experiment preparing it, else why should it stay in the open jar like water. It is about $2\frac{1}{2}$ times as heavy as air.

Chlorine is soluble in water. Let us take a bottle half filled with water and fill the other half with chlorine gas. Let us cover the mouth of the bottle closely with the palm of the hand and shake its contents violently. Nothing seems to have changed. But let us take the hand from the mouth of the bottle: a dull report is heard at the moment. Now this sound is caused by air rushing violently into the bottle; but air could not get in unless the chlorine had been removed. What has removed it? *The water must have dissolved it.* Every

cubic inch of cold water can dissolve more than two cubic inches of chlorine gas.

Describe an experiment with chlorine and hydrogen.—Let a strong but transparent glass bottle be half filled with hydrogen and the other half filled with chlorine. Cover it with cloth and remove the bottle to a place where the bright rays of the sun can fall upon it. Very cautiously take away the covering. A startling report like that of a small gun will be quickly heard.

What has happened? If we examine the contents of the bottle we shall find no chlorine, no hydrogen. We may find hydrochloric acid instead of the gases we put in.

What does the experiment show?—We may learn from this experiment that *chlorine has a strong attraction for hydrogen.* This attraction brings the two gases violently together and binds them both into one new substance—*hydrochloric acid.*

Describe an experiment with a burning taper.—Let a burning taper be lowered into a jar of this gas. A curious set of things quickly happens. The white flame of the taper is at once put out; a red flame very quickly takes its place, while large volumes of black smoke are given off. Let us examine these things further.

What is the black smoke?—The black smoke is chiefly carbon. The wax is made mostly of carbon and hydrogen, and, while burning with the red flame in chlorine, its carbon flies off as smoke.

What do we learn from this?—We see here that chlorine does not readily combine with carbon; or, as the chemist tells it, *chlorine has little attraction for carbon.*

What causes the red flame?—The hydrogen of the wax is seized by the chlorine in the jar, and the red flame is caused by their violent union. Here we have a fine illustration of the fact learned before, that chlorine has a strong attraction for hydrogen.

Describe the experiment with chlorine and ink.—Let us fill a goblet half full of water and then put in black ink enough to give the liquid a good deep color. Then let us pour some of the solution of chlorine and water into the black liquid and we shall see the black color disappear, slowly it may be, but entirely. The dark colored liquid is bleached.

May other coloring matter be used with a similar result?—Red ink will be bleached in the same way; so will blue litmus.

If you have a few chips of logwood you can make the following experiment: Pour some boiling water upon the chips; they will give up their coloring matter and you will have a deep red liquid. Add chlorine solution to this liquid and its red color will quickly disappear.

Or you may take the most deeply and gaily colored flower to be found, and hang it in a jar full of moist chlorine gas. Its beautiful colors will gradually fade away until only a dull white is left in their places.

Why does chlorine destroy colors?—The chemist easily explains this action. He says that hydrogen is one of the elements in most coloring matters, and that the chlorine can take this element away from them. The colors are thus decomposed and new substances without color are formed.

In some cases the action may not be exactly like this. The chlorine may set oxygen free in the substance, and the oxygen may then attack and decompose the coloring matter.

What use is made of the bleaching power of chlorine?—The art of bleaching cotton cloth depends on this power of chlorine. The dingy yellow cloth is first thoroughly washed and then steeped in a mixture which gives off chlorine gas. The gas attacks the color, conquers it, and then, when the cloth is afterward washed, it is white.

The rags out of which white paper is to be made are first bleached by the action of chlorine.

What will chlorine remove besides color?—Bad odors are destroyed by chlorine. Even those which come from decaying animal and vegetable matter are too weak to resist its power. Hence chlorine is called a *disinfectant*. It is of very great value in sick-rooms and hospitals where unpleasant and unwholesome odors are likely to be met.

Why are bad odors destroyed by chlorine?—The action is like that in bleaching. Hydrogen is an element in the substances having the odor. It is taken out by chlorine, and the odor is thus removed.

We see then how very useful to man is the strong attraction which exists between chlorine and hydrogen.

Describe the experiment with chlorine and antimony. — Antimony is a brittle, shining metal, and one of the last things a person would expect to see burning. But let some powdered antimony be sprinkled into a tall jar full of chlorine gas, and it will fall to the bottom in a shower of vivid sparks, (Fig. 49.) Every little grain of metal takes fire when it touches the chlorine; they all burn away and leave a dense white vapor in the jar.

Fig. 49.

What does this show?—This shows that there is a

strong attraction between chlorine and antimony. The white vapor is a compound of these two elements.

Is there strong attraction between chlorine and other metals?—Let other metals be used instead of antimony; a similar action will take place, showing that chlorine has a strong attraction for them also.

Are these compounds of chlorine and metals common?—Compounds of chlorine with some metals are scattered very widely in the sea and in the rocks and soils. Such compounds are called *chlorides,* because they contain chlorine. The chloride containing silver is found in many parts of the world; it is a rich and abundant ore in Chili.

What is common salt?—Common salt is a chloride; in chemistry it is called *sodic chloride,* because it is a compound of *sodium* and *chlorine.*

Where is it found in nature?—Vast quantities of salt are dissolved in the waters of the ocean. Small quantities are scattered in minute grains throughout the soil almost everywhere, and even in the air this substance is constantly floating in minute particles.

Water from the clouds soaking through soils and rocks where sodic chloride is to be met in more than usual quantities dissolves it and becomes salt water. This water may be found in springs or caught in wells, and it is by evaporating it that nearly all the salt of commerce is obtained.

BROMINE.

A little more than half a century after the discovery of chlorine—it was in the year 1826—M. Balard, a French chemist, found another element with properties much like those of chlorine. Its odor was found to be so strong that in honor of this characteristic the element was called *bromine.* The word is from the Greek word *bromos,* which means *stench.*

Where is bromine to be found?—Bromine is not very

abundant, but it does exist in the waters of some mineral springs, and in larger quantities in the waters of the sea. It is always found in combination, and its compounds are called *bromides.*

What are some of its properties?—Bromine is a *liquid.* A very gentle heat changes it to gas. It has a beautiful dark red color.

This element combines easily with hydrogen and with metals; in this respect it is like chlorine, and like that element it is able to remove colors and to destroy bad odors.

IODINE.

M. Courtois was a chemical manufacturer in Paris. He was engaged in making soda and was using the ashes of sea weeds for this purpose. A dark colored liquid was left in his kettles and attacked the metal of which they were made. When some sulphuric acid was put with it, this liquid gave up a substance which when heated changed to a beautiful violet-colored vapor. This proved to be a new element, and it was called *iodine.* This word, from the Greek word *iodos,* means *violet-colored.*

Fig. 50.

Where is iodine to be found?—Iodine is a constituent of sea-plants, as we may know from the story of its discovery. The sea contains it in small quantities, and so do the waters of some mineral springs. It is an element in sponges, and

in oysters, and in some fishes. It is always found combined with other substances.

What are some of its properties?—Iodine is a *solid*. A gentle heat melts it and a little higher temperature changes it into its beautiful vapor.

Water dissolves it, but a single grain will take no less than 7000 grains of water to dissolve it. How small this proportion of iodine! and yet it gives to the whole body of the water a brownish yellow color! Alcohol will dissolve it in large proportions.

With what elements does iodine readily combine?—Iodine combines with hydrogen and with many metals. In this respect it is much like chlorine and bromine. Its compounds are called *iodides*.

Some of its compounds with the metals are remarkable for their very brilliant colors.

How may we produce the compound of iodine and mercury?—Let us put a little *potassic iodide*, which is a compound of potassium and iodine, into a test-glass partly full of water, and then we will add a little solution of *corrosive sublimate*, which is a compound of mercury and chlorine. No sooner do the two liquids touch each other than clouds of a new bright yellow-colored substance are seen. But the yellow color will not stay; it gradually changes into a beautiful scarlet. This scarlet-colored substance is a compound of *mercury* and *iodine*, and it is called *mercuric iodide*.

What is the test for iodine?—There is one thing which can be done by iodine and which nothing else can do. Notice the experiment:

Take a sheet of paper, and with a small brush write upon it your name with a solution of starch. Next throw some iodine upon a hot surface; it will be quickly changed to vapor. Hold the paper in this vapor so that the starch will be struck by it, and behold! your name comes out into

sight at once, surprising you by the beautiful *blue color* of its lines.

Such a blue is always produced when starch and the element iodine come in contact. Let us turn the sentence around and notice that wherever this blue color is formed, there starch and iodine have come in contact. In this way starch becomes the "test" for the presence of iodine.

What are the uses of iodine?—The physician finds iodine very useful as a medicine. It is of great service in curing certain diseases of the throat.

The photographer finds it very valuable in the art of picture-making.

The element itself is sometimes used in medicine, but the compounds of the elements are more generally used in the arts.

SULPHUR.

Sulphur is a very common substance. We know it as a fine yellow powder, and as "rolls" or "sticks," and have doubtless seen it put to some of its many uses. Who first discovered it we cannot tell, for it seems to have been known and used in the most ancient days of which we find any account. Though so common a substance, yet there are some things about it which the young are not likely to know, but which they will be ashamed not to know when they are older.

Where is sulphur found?—It is a rare thing to find an element in the earth not combined with others, but *sulphur* is one of the few which are found free. It is found in countries where there are volcanoes, or where these fire-mountains have been active in time past. In the island of Sicily it is found in large beds in the earth, and immense quantities are there taken from mines to be sent all over the world.

In what other condition is sulphur found?—Sulphur is found *combined with metals* in the rocks and soils almost everywhere. These compounds are called *sulphides.*

The sulphide of iron is a brassy-looking substance very common in many rocks. It is often found in the form of little cubes, as perfect as if they had been chiselled by an artist.

Sometimes it is found in the form of thin, shining, yellow scales. There is another metal, you know, whose color is yellow, a very different thing, and yet ignorant people have often been sadly deceived by this worthless compound; on this account it has been called "fool's gold." Iron pyrites is its better name.

Are any of these sulphides valuable?—They are not all as worthless as fool's gold. These sulphides are often the substances from which the metals are themselves obtained.

The common metal, lead, is never found free in the earth. The substance found in the earth from which this metal is taken is called *galena;* but what is galena? Simply a compound of lead and sulphur.

Silver and copper and zinc are also among useful metals found in combination with sulphur in the rocks.

From what source is the sulphur in commerce obtained?—The mines of Sicily and of Italy yield the larger part of all the vast amount of sulphur used in the world. It is said that these mines give out no less than 80,000 tons of sulphur every year!

Is it ready for use as it comes from the mines?—In these places the sulphur is found, as we have said, *free,* that is uncombined, but yet it is very far from being ready for the market. It is not in *combination,* but it is *mixed* with a great deal of earthy impurities from which it must be separated.

How is it purified?—Sulphur is easily changed into vapor by heat; the earthy impurities are not. Let the mixture be heated, then, and the sulphur vapor will pass away and leave the impurities behind. The vapor, being cooled again, is sulphur very much more free from earthy matter than before.

It is heated a second time to remove the impurities which the first process did not. This time the vapor is run into a large chamber, and it is condensed upon the cold walls in very fine powder. This powder is the "flowers of sulphur" which is so common.

When the chamber is smaller its walls become too hot to collect the powder; it is then melted and the liquid runs down upon the floor. It runs into channels in the floor which lead it out of the chamber into moulds. In this way the familiar sticks of "roll brimstone" are made for the market.

Describe the experiment of melting sulphur in a paper dish.—Put some flowers of sulphur upon a piece of common paper and hold the paper over the flame of a lamp; the sulphur may be melted without the paper being scorched.

What does this show?—This shows that sulphur melts at some low temperature.

Other experiments have shown that the melting of sulphur begins at 230° F. This is only 18° above the temperature of boiling water.

What change is produced by heating the melted sulphur?—When melted at as low temperature as it can be, sulphur is a very pretty, limpid, yellow fluid. A curious change occurs if it be heated to a higher temperature. At 270° it begins to grow dark-colored and to get thick. Darker and thicker it becomes as it gets hotter, until, at about 500°, it is almost black, and is so very viscid that it will not flow from the vessel even if turned bottom upward.

What happens if still more heat is applied?—Make the hot sulphur still hotter and the dark-colored, almost solid substance, grows less viscid again; it can be poured from the vessel very much like thick sirup.

What happens if this hot sulphur is suddenly cooled?—Another strange change happens. Let this very hot sulphur be poured into cold water; it cools into a substance which looks like india rubber. If we handle it, we find that it is like india rubber in other things besides its color; it is *tough* and *elastic*. Who would think it to be the same substance that a few minutes before was a yellow powder!

At what temperature will sulphur take fire?—Heated in the air to about 500° sulphur takes fire and burns with a pale blue flame. This is a low temperature to produce flame; most bodies need to be heated up to about 1000° before their flame appears.

What new substance is formed when sulphur burns?—Sulphur and the oxygen of the air when hot attract each other with much force. Their little particles strike each other so violently that fire is produced. They then cling together and are henceforth known as neither sulphur nor oxygen, but as a new thing called *sulphurous oxide.*

This substance is formed when a lucifer match begins to burn, and every one knows its odor whether he has ever heard its name or not. It is a colorless gas.

Is this compound useful?—The gas is very soluble in water and the solution is used for many purposes. It is called *sulphurous acid.*

The gas has a strong bleaching power, and it is used in bleaching straw and woolen goods. A milliner wishes to whiten a straw bonnet; she may hang it in a small chamber, which is sometimes nothing more than a barrel turned bottom upward, and then burn some sulphur under it. The fumes of sulphurous oxide enter the straw, destroy its color, and leave the bonnet white.

Name another valuable compound of sulphur.—*Sulphuric acid* is one of the most important compounds known. Its elements are sulphur, oxygen and hydrogen. Notice how little its name differs from that of the other compound mentioned. That is sulphurous acid ; this is sulphuric acid. The names are so much alike because the two things are made up of the same elements—sulphur, oxygen and hydrogen.

In the first name the word sulphur has **ous** added to it; in the second, **ic**. This is so because there is a less proportion of oxygen in the first than in the second.

The endings *ous* and *ic* are very often used in chemical names when two substances contain the same elements. Remember that **ous** *is used in the name of that which contains a* LESS *proportion of the element.*

What kind of a substance is sulphuric acid?—Sulphuric acid is a heavy, oily-looking liquid ; for this reason it is often called *oil of vitriol.* If we taste it we find it to be sourer than the strongest vinegar. If we touch it we find our fingers smarting almost as if it had been fire. If we drop it upon our garments we find them turning red wherever touched by it, and that, some days after, the red spots crumble into holes.

Describe a simple experiment?—Let us plunge a slender rod of wood into a vessel of oil of vitriol. It comes out as black as if it had been scorched. Indeed the wood is changed very much as it would be by fire. It is the carbon of the wood which the acid leaves to show the black color which we see.

What do we learn from this?—We may learn from this that sulphuric acid has a strong attraction for the hydrogen and oxygen of the wood. It takes these elements away and leaves the carbon behind.

In what other way does this acid show its attraction for these elements?—The following experiment

will help us to remember this striking character of sulphuric acid.

Into a very thin glass vessel, called a beaker glass, pour some sulphuric acid, and then add about one-fourth as much water. The beaker quickly becomes too hot to handle! Take a test-tube partly filled with alcohol, and plunge it into the mixture; the alcohol will boil almost as quickly as if it were held over a lamp flame!

Why this strong heat without fire? It is because the acid and the water have suddenly combined, and it is the *sign* by which the acid tells us how ready it is to combine with hydrogen and oxygen—the elements of water.

Is this attraction used to any advantage by the chemist?—The chemist very often needs the gases with which he works to be perfectly dry; he remembers this strong attraction between sulphuric acid and the elements of water, and makes his gas bubble through some of the acid. It comes off dry.

What are some other uses of this acid?—Sulphuric acid is used in making a great many other substances used in the arts, such as soap, soda, alum, and many other kinds of chemicals.

It is used in coloring cloth, in printing calico, and then, at other times, in bleaching them.

Many *thousand tons a week* of sulphuric acid are made and distributed over the world to be used for a multitude of purposes in the arts.

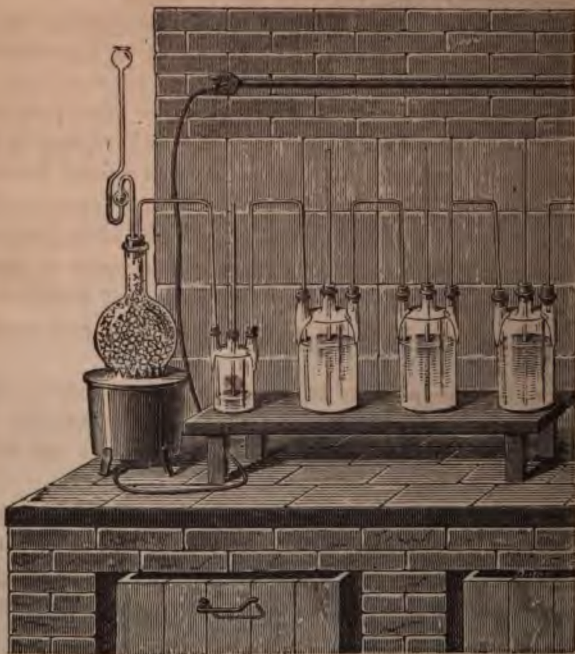
What compound does sulphur and hydrogen form?—Sulphur and hydrogen are found combined in a substance called *sulphuretted hydrogen.* It is a colorless gas with an odor like that of decaying eggs.

For what is this gas used?—It is a very useful gas to the chemist in his laboratory work. It is a sort of tell-tale, ready to inform the chemist of the presence of certain me-

tals in compounds, where they may be hidden. It does this by giving up its sulphur to the metal in solution, and thus forming a new substance, whose color generally reveals the the name of the metal itself.

Where is it found in nature?—This gas is found in the waters of "sulphur springs." All the sulphur which such springs contain is in the form of this gas. They owe their nauseous taste and odor to sulphuretted hydrogen dissolved in their waters.

Fig 51,



The waters of Sharon and Avon are so-called sulphur waters; those of Harrowgate, in England, are noted examples

of the same kind. A solution of this gas may be made by passing it through water in bottles arranged as seen in Fig. 51. Being set free in the flask at the left it bubbles through the water of the four bottles in succession. The chemist often uses this solution instead of the gas itself.

This nauseous gas is often given off by decaying animal and vegetable matter in many places.

PHOSPHORUS.

We come now to spend a little time with an element which was discovered more than 200 years ago. In 1669 a man by the name of Brandt, in Hamburg, was making experiments in hope to find the "philosopher's stone," by the touch of which he expected to be able to turn any substance into gold. Of course he found no such thing as that, but he did find a very extraordinary substance. It was a waxy looking solid, yellow by daylight, but shining with a pearly white light *in the dark*. It burned furiously at the least provocation by warmth, and, on the whole, was so strange in its actions that the superstitious chose to name it "The Son of Satan." It proved to be an element, and it is called phosphorus.

Where is phosphorus to be found in nature?—This curious element is never found free in nature, but, on the other hand, its compounds are to be met in rocks and soils, in plants, and in animals.

What are these compounds called?—The compounds thus widely distributed are called *phosphates*. Their elements are *phosphorus, oxygen* and a *metal*. The one most abundant is the *calcic* phosphate. It has this name because it contains the metal *calcium* with the oxygen and phosphorus.

In what part of plants is this element chiefly found?—In the corn plant, for example, we find phosphorus in its

kernels. In wheat and in oats, we find it in the grains, more than in other parts. It is generally true, as in these cases, that *phosphorus is an important element in the seeds of plants.*

In what part of animals is it most abundant?—This element is abundant in the *bones* of animals. Let us gain some idea of its quantity there. Almost one half of the weight of the bones in an animal is calcic phosphate, and about one fourth of the calcic phosphate is phosphorus. The phosphorus you may notice is about *one eighth* of the weight of bone.

Now the skeleton of a man weighs perhaps as much as twelve pounds. In such a frame there would be about *a pound and a half* of pure phosphorus.

In what other parts of an animal is this element to be found?—This element is always present in the brain and in the nerves of animals. That it is of the highest importance to these organs is shown by the fact that unless an animal eats food containing it, so that these parts can be supplied with phosphorus, it becomes torpid.

From what is phosphorus obtained for the market?—Phosphorus is manufactured from bones in considerable quantity for use in the arts.

The bones are first burned; they become white and very brittle. When they are afterward crushed the powder is called *bone ash.* From this the phosphorus is obtained. It comes to market in the form of round "sticks" four or five inches long and about a half inch in diameter.

What are some of its properties?—In color it is like yellow wax, but it is much harder than that body. It has the curious power to *shine in the dark;* it gives a most delicate pearl-white light.

But its most fearful quality is its *combustibility.* A safe and easy experiment shows how easily it is set on fire. Thus: put a bit of dry yellow phosphorus between two thicknesses

of paper and place the little bundle on the floor. Then rub it with the boot and it will burst into flame.

To rub it with the warm fingers will inflame it. The friction of a knife blade in cutting it will sometimes produce heat enough to start the furious burning of this strange element.

How can such a substance be safely handled? It is kept under water, and it ought to be cut under water to avoid accident.

How may it be changed by heat?—Let some phosphorus be put into a vessel, full of carbonic dioxide or nitrogen, which will not act upon it, and then let heat be applied. In this case the phosphorus will not burn, no matter how hot it becomes. But at a temperature about 480° F. a curious change takes place. "The melted phosphorus becomes solid, opaque, and of a deep red color."

This "red phosphorus" may be exposed to the air and handled with very little danger.

What is one of the uses of phosphorus?—Large quantities of phosphorus are used in making *friction matches.* The ends of the matches are tipped with a paste containing phosphorus. By rubbing them upon a rough surface, friction gives heat enough to set this phosphorus on fire. But who has not noticed the *sulphur* which is to be seen on the wood of the match near its end? Why is it there? It is because so little phosphorus as may be in the paste, at the end, may burn *without being hot enough* to set the wood ablaze. It will be hot enough however to set sulphur on fire, because it takes only a low temperature to do that, and the burning sulphur will be hot enough to inflame the wood.

What are "safety matches?"—In the tip of a safety match there is no phosphorus, but there is a substance which will cause that substance to burn if it have a chance to do so. Now on the other side of the match-box there is

a paper smeared over with a mixture containing some powdered "red phosphorus." Let the match be rubbed on this and it will be set on fire, but it may be rubbed over any other rough surface without danger.

What are "parlor matches?"—Parlor matches are made without sulphur, and we may use them without enduring the suffocating odor of the common "lucifer."

Let us describe a little experiment. Take a bit of potassic chlorate about as large as a grain of wheat, and another bit of phosphorus about the same size. Wrap them closely together in a piece of brown paper and lay the little bundle on an anvil, or some other hard, smooth surface. Strike it a smart blow with a hammer; a sharp explosion instantly occurs, and the paper is likely to be set on fire.

Now in the tip of a parlor match there is potassic chlorate and phosphorus. Strike it on a rough surface; it explodes and bursts into flame.

To what is the burning of phosphorus due?—Phosphorus burns only when in the presence of oxygen. It is the very strong attraction between these elements which causes the combustion.

What substance is formed by their union?—All the compounds of oxygen which contain one other element are called *oxides;* its compound with phosphorus is an oxide, and because this oxide contains phosphorus it is called *phosphoric oxide.*

How may we produce it?—Let us describe the experiment. Put a piece of dry phosphorus upon a little dish and stand the dish in the middle of a large dinner plate. Touch the phosphorus with a hot wire and quickly cover it with a large dry gas jar. A beautiful light fills the jar at once. Masses of milk-white vapor are quickly formed, and very soon snow-white flakes will be seen, some on the sides of the jar, others falling, like snow in a little snow-storm, to the plate below.

This snow-white solid is *phosphoric oxide;* you will remember why this name was given to it.

Describe the action of water upon it.—Pour a little water upon the plate so that it shall touch the white oxide, and notice : a hissing sound is heard, as if a hot iron had been plunged in water, while, at the same instant, the oxide disappears instantly.

Now what does this mean? Just this: the phosphoric oxide has combined with the water, and the curious action shows us how ready these two substances are to embrace each other.

What is the new compound?—This new compound is called *phosphoric acid.* It is intensely acid, that is, sour to the taste, and its elements are phosphorus, oxygen and hydrogen.

ARSENIC.

Every person is familiar with "arsenic" as the name of a very powerful poison, and many have seen the white substance, so deadly, which bears the name. But before we begin the study of arsenic let us learn that the white substance just mentioned *is not arsenic* itself, but a compound of that substance.

What is arsenic?—Arsenic is an element. It is a solid substance with a steel-gray color, and a lustre like the metals. It is very brittle and easily powdered. Its powder is sometimes sold under the false name, "cobalt," to be used as a fly-powder. It is an active poison.

Where is arsenic to be found?—Arsenic is found in the earth. Neither plants nor animals contain this element naturally, so that if a chemist finds it in an animal substance he is very sure that it has been placed there for some other purpose than to promote the growth of the body.

This element is sometimes found free, but such *native* arse-

nic is not common. It is oftener found combined with metals and with sulphur.

In commerce we find the compound of arsenic and oxygen, commonly called "arsenic," but which is properly called "*arsenous oxide.*"

How is arsenous oxide obtained?—In Silesia, Germany, there is found a mineral which contains arsenic with iron and sulphur; its curious name is *mispickel.* From this mineral most of the arsenous oxide of commerce is obtained.

To get the oxide from mispickel, the mineral is *roasted,* that is to say, it is heated in a current of air. The hot oxygen of the air takes the arsenic from the hot mineral, and the two elements combine; arsenous oxide is the result.

What are some of its properties?—This substance is a white solid; it can be dissolved in hot water, in cold water not so well. Its solution is almost tasteless and colorless, and without odor. It is a most fearful poison.

But while this compound is so fatal to the life of an animal, it has the strange power to prevent the decay of its body. It is used to destroy rats, mice, insects, and sometimes for the terrible purpose of taking the lives of men. On the other hand, it is made to do good service in the preservation of the stuffed or dried objects of natural history to be found in museums.

Can the presence of arsenic be proved with certainty?—The chemist has studied the compounds of this deadly element, until he has so well learned their characters that he can tell with absolute certainty whether they are present in any suspected substance.

Name one of the most satisfactory tests.—There are many processes by which the poison of arsenic can be tested; we will not now try to study them all. That known as *Marsh's test* is among the very best. Let us try to understand this one.

Describe an experiment.—Let some pure zinc, pure

water, and pure sulphuric acid be put into a bottle together. Hydrogen gas will be set free, and if the apparatus is properly arranged (Fig. 52) we may set fire to the hydrogen as it escapes from the small end of a glass tube, and thus obtain an almost colorless flame.

Fig. 52.

Let us next pour a few drops of a solution of arsenic oxide through the funnel tube into the bottle. The flame is colorless no longer ; it becomes larger and assumes a livid white ness. Now why is this so?

Explain this change.—The explanation is ready. Hydrogen and arsenic have a strong attraction for each other, and in this experiment the arsenic leaves the oxygen with which it was combined, and seizes the hydrogen which is being set free. They form a new gas, and it is this new compound of hydrogen and arsenic which burns with such a death-like pallid flame.

This new gas is called *arseniuretted hydrogen.*

What happens when this gas burns?—When this gas burns it is decomposed. Its hydrogen and its arsenic leave each other and combine with the hot oxygen of the air.

How may its arsenic be caught?—Now let a cold white plate be held in the livid flame ; a small brownish black spot will quickly form upon it. This deposit is *the element—arsenic.*

What facts seem to be proved by these experiments?—Two facts seem to be proved by what takes place in these

experiments. The first is that *hydrogen is able to take the arsenic out of the compounds which contain it.* The second is that, *the arseniuretted hydrogen will give the arsenic up again when heated.*

Upon these two facts *Marsh's test* is based.

Describe the operation in Marsh's test.—In the first place there is a bottle containing some fragments of pure zinc and some pure water. Pure sulphuric acid is poured through the funnel-tube and hydrogen gas is set free in the bottle. Now trace this gas. It goes first through a bent tube into an upright jar. In this jar is some calcic chloride. This substance is used in order to dry the gas. The hydrogen, pure and dry, passes through a long horizontal tube away from the jar, and is set on fire as it issues from the distant end.

When the hydrogen gas is burning very steadily, the liquid supposed to contain arsenic is poured into the bottle.

We know what must take place if arsenic is present, but let us repeat it. The hydrogen will take the arsenic and form arseniuretted hydrogen gas, and this gas, pure and dry, will burn at the end of the tube.

How will the arsenic show its presence?—If very much arsenic is present the color of the flame will show it; but whether the flame looks livid or not, the chemist will hold a cold piece of white porcelain across the flame, and if any arsenic is there a brownish black stain will be left upon the white surface. This stain is so different from any that can be produced by other things that the chemist need never err; it is a sure proof that the substance being examined contains the poisonous substance.

How little arsenic will be enough to show its presence in this way?—It is said that even when so little as $\frac{1}{10000}$ of a grain in one hundred grains by measure of the solution is used, there will be arsenic enough to show itself distinctly by Marsh's test.

IRON.

In the most ancient of all histories we are told of a man who was a cunning workman in brass and iron. It was Tubal Cain. He was the great-grandson of the son of Adam. Think, then, in what ancient times this valuable metal was known and used.

Fig. 53.

Where is iron found in nature?—Iron is found in the rocks, in the soil, in plants, and the bodies of animals. No other metal seems to be so generally distributed as iron.

In what condition is it found?—Very rarely indeed is iron found free. In combination with other elements it exists in the earth and in the rocks. These earthy and rocky compounds are called *ores* of the metal, and from these all the iron ever used, from the time of *Tubal Cain* until now, has been obtained.

The picture shows an ancient furnace in which ores were melted and compelled to give up their metal. It was a rude affair, but it was used in rude times. We shall soon see what more elegant structures have taken its place in this enlightened age.

What are the principal ores of iron?—The ores of iron are very numerous; we will not try to notice all. Those from which the metal is chiefly obtained may be named as follows: Magnetite, hematite, carbonate of iron.

What is magnetite?—Magnetite is a compound of iron and oxygen. It has a shining black color, and is sometimes called *black oxide of iron.* Pieces of this ore are sometimes found which are strongly magnetic; the *loadstone*, of which we often read, is nothing more than this. This strange property has given the ore the name it bears.

This "magnetic iron ore" is very abundant in this country. There are mountains made of it in Missouri, and vast beds of richest quality are found in New York.

What is hematite?—Hematite is another compound of iron and oxygen, but these elements are together in different proportions from what they are in the other ore. It contains less iron.

Hematite is sometimes red and sometimes brown, and sometimes brownish yellow. It is found crystallized often, and the crystals are neither red, nor brown, nor yellow, but of a dark steel-grey. Their shapes are often very curious and beautiful.

What is carbonate of iron?—This ore is made up of iron, oxygen and carbon. It is generally mingled with clay, and some other earthy matters, and on this account it is often called *clay-iron stone.*

How is iron obtained from these ores?—The iron is obtained from these ores by a process which is called *smelt-*

ing. The ore is mixed with coal and limestone, and this mixture is heated intensely. Let us study the operation carefully.

What kind of a furnace is needed?—The operation requires a very high temperature. No fire will be hot enough which burns only by the *draught* of a chimney. We all know how much faster and of course hotter a common fire will burn when fanned. So the furnace for smelting iron ores is one which has a strong blast of air driven into it to drive the fire into its greatest fury. Such a furnace is called a *blast furnace.*

Fig. 54.

The picture (Fig. 54) will help us to know how one of these great furnaces looks, and the other picture (Fig. 55) shows us how the inside is shaped.

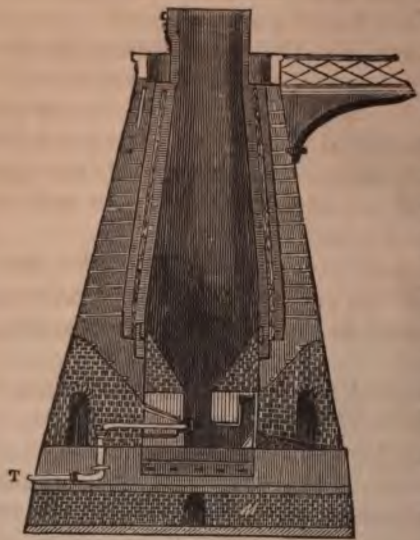
What is the size of the blast furnace?—These furnaces are of different sizes of course, but the smallest is quite a large building. They are from 50 feet to 100 feet in height, and inside, at their widest place, they are from 12 feet to 18 feet in diameter.

What is the inside form of the furnace?—Figure 55 represents the general shape of the inside of a blast furnace. Notice that its largest place is about one fourth the distance

from the bottom toward the top. Next notice that from this part the walls slope both ways so that the room is small both at the top and bottom.

How is the furnace charged?—Everything that goes into the furnace is thrown in at the top. First a layer of fuel then a layer of crushed ore, then a layer of broken limestone and then another of fuel, and so on alternating the layers until the furnace is filled.

Fig. 55.



What about the fire?—The fire is started at the bottom and is driven by a blast of air. Notice in Fig. 55, a pipe reaching through the bottom of the furnace into the chamber; there are usually three. These pipes bring air from a *blowing machine*, and the air is driven through by the power of a steam engine. These blast pipes have the curious name, *tuyères*.

What happens in the furnace? — The ore is decomposed by the terrible heat and the carbon of the burning fuel.

The carbon combines with the oxygen of the ore and the iron is thus set free.

The earthy parts of the ore and the limestone mixed with them melt together and form a glassy-looking substance called *slag*.

The iron seizes a little carbon, then melts and runs down

to the bottom of the furnace into a sort of chamber prepared to catch it.

The melted slag also runs down to the bottom, but it is lighter than the metal and floats upon its surface like a scum.

What becomes of the melted metal?—In front of the furnace is a large level bed of sand. A channel is scooped through the middle of this bed, and it reaches all the way from the bed to the hearth of the furnace. From the large channel in the middle of the bed of sand there are smaller ones reaching out each side, and then from these there are other branches about three feet long and three or four inches wide. Look at the picture (Fig. 54) and you will see the arrangement of this central channel and its branches also.

Now about every twelve hours the furnace is opened at the bottom for the melted metal to run out. Where can it go? It has no choice of places; it must flow down through the large channel and off into all its branches in the bed of sand. There it is allowed to cool.

What is the iron thus obtained called?—The iron thus obtained is the *cast iron* of commerce. The short bars cast in the sand are known as *pigs*. Indeed, the cast iron is often called *pig-iron*.

What are the essential constituents of cast iron?—Iron and carbon make up the pure cast iron. The carbon is a small part of it, only from two pounds to four pounds in a hundred pounds of metal. All the rest of the 100 pounds is iron. Cast iron *always* contains the small proportion of carbon, and it has properties quite different from those of pure iron. But cast iron is itself seldom pure.

What is another substance in cast iron?—Silicon is also present in cast iron. The quantity of this constituent is very small. Sometimes it is not more than *a thousandth* part of the weight of the metal. At other times it is as much as *one twentieth*. But little as it is, it affects the quality of the iron. Too much of it makes the iron weaker.

Name another substance in cast iron.—Phosphorus is also found in cast iron. The proportion of this impurity is very small; not generally more than the $\frac{1}{100}$ part of the weight of the metal. It is said to harden the iron and make it more easily melted.

Name yet another impurity of cast iron.—Sulphur is not often absent from cast iron, but it is seldom present in so large a quantity as the $\frac{1}{50}$ part of the weight of the metal.

The presence of sulphur is said to weaken the cast iron in very high degree.

A great quantity of cast-iron is used for many purposes in the arts. In order to make it into useful articles it must be melted, and the melted metal is then poured into moulds. This operation is called *casting*.

Now if you will look at this picture (Fig. 56) you will be able to understand how this is done.

What kind of a furnace is used?—It needs a strong heat to melt pig-iron, and the furnace is such as to let the fire be driven by blasts of air. Yet it is very different from the blast furnace. It is called a *cupola furnace*.

Describe the cupola furnace.—This furnace looks like a large iron cylinder with a door at some distance above the bottom for the iron and the fuel to be put into it, and a hole, called the *tap-hole*, at the bottom for the melted metal to come out. But it is not built of iron; it is made of fire-bricks to withstand the heat, and only a thick casing of iron is bound over the outside.

That you may have a clearer idea of its size notice the following description: "For melting five tons of cast-iron the cupola furnace is nine feet high and 3½ feet in diameter, clear of the lining."

How are useful articles of cast-iron made?—In the

first place moulds are made in sand, just exactly the size and shape of the article.

Then, when the melted cast-iron is ready in the furnace, the tap-hole is opened. A fiery stream of liquid iron pours out; it is caught in *ladles* by the workmen, who hurry it away to the moulds. The fluid metal runs into every little groove and corner of the mould and there hardens into the desired form.

How are these castings protected from rust?—The article—we will suppose it to be an iron kettle for the kitchen stove—is brushed over with linseed oil and then hung over a smoky fire. It is afterward dipped into turpentine. In this way it receives a shining black coat which protects the iron from the rusting action of the air.

Cast-iron as it comes from the smelting-furnace is not fit to be used for some of the many purposes to which iron is put in the arts.

What must be done to make iron of better quality?—When iron of greater tenacity and strength is needed, cast iron must be purified. Its carbon, its sulphur, its phosphorus, its manganese, if it have any, and its silicon, must be taken away.

What element is used to do this?—Oxygen is the element which can rob the iron of these impurities. But it will not do this unless it can come in contact with all parts of the melted metal. Let us see how this is brought about.

What kind of a furnace is used?—The furnace used for this work is called a *reverberatory furnace.* Look at Fig. 57 and you will easily trace the following account:

Describe the process.—The cast iron is placed upon a large hearth, D; the fire is built in a separate part of the chamber. Flame and hot gases from the fire strike against the arched roof of the furnace, and the intense heat is thrown

from the roof down upon the cast iron. In a little time the iron begins to soften, and at length it becomes a pasty mass of half-melted metal. Then the furnace-man unstops a hole, B, thrusts a paddle through into the pasty mass, and working this paddle about (puddling) he thoroughly stirs the metal, so that all parts of it are slowly brought in contact with the hot air at the surface.

Fig. 57.

What happens then?—The hot oxygen of the air seizes the impurities, one after another, and forms new compounds. Some of these form a liquid slag, which is drawn off out of the furnace, at *b*, while others are gases which pass up and out of the high chimney.

What is the result?—The result is that the iron is soon left almost alone in the furnace. A large part of its carbon has been burned away and has gone off up the chimney. A large part of the other impurities are also burned; but some of the slag thus made is still mixed with the purified iron.

What is next done?—The furnace-man then lifts out a ball of this pasty iron, weighing perhaps 60 pounds, or even more, and puts it under the heavy blows of an immense hammer, or sometimes between the rollers of a tremendous squeezer. In this way the impurities which are

still mixed with the iron are pounded or squeezed out, so that the iron is left more pure and compact.

How is the form of the block then changed?—The mass of iron is then forced through grooves between two strong rollers. The tremendous pressure of these rollers squeezes the mass out into a long and slender rod or bar.

Is anything more to be done?—For the best quality of *bar-iron*, as this form is often called, the bars are cut into short lengths and bound together in bundles to be heated over again and rolled a second time into bars. By repeating these efforts the purest and strongest iron to be found in commerce is obtained.

What is this iron called?—It is called *bar-iron*, sometimes *wrought iron*, and often *malleable iron*.

Neither *cast iron* nor *wrought iron* has the qualities which render iron useful in all the various ways in which this metal is employed; a third form is *steel*.

What difference between steel and the two other forms of iron?—The difference between steel and the other two kinds of iron is best shown by the use of fire and water.

Let wrought iron be strongly heated and then suddenly cooled by a plunge into cold water. Very little if any change will be produced.

Let steel be treated in the same way and it will be made almost as hard as diamond, and so brittle that it will snap before it will bend.

Let this brittle steel be heated again to a point below red-heat and then cooled, and it is softened somewhat, and, what is more remarkable, it is made so elastic that it will bend rather than break, and spring back again when released from the force.

Cast iron may be hardened as much as steel may be, but it cannot be made elastic.

What is the difference in their composition?—Each of these three is composed of iron and carbon, but carefully notice the difference. *Cast-iron* contains the largest proportion of carbon, *wrought iron* the smallest, and *steel* a proportion between the other two.

In what way then would it seem, that steel might be made?—It would seem, then, that steel could be made in two ways:

By *taking away* some carbon from cast iron.

By *adding* some carbon to wrought iron.

Steel, so largely used in the arts, is made in both these ways.

How is steel made from cast-iron?—From two to six tons of cast-iron is melted and then run into a large globe-shaped vessel made of a substance which will not melt at the highest heat to be attained. In the bottom of this vessel there are many holes, and a strong blast of air is driven through them. The air bubbles up through the melted metal, and a most furious burning begins. The oxygen attacks the silicon, and the sulphur, and the carbon, and some of the iron also, and burns them into compounds with itself.

In this way the iron is partly purified, but in giving up these elements it goes too far and gives away so much carbon that too little is left. By adding some cast iron to the purrified mass enough carbon is given back to change the whole into steel.

The globe-shaped vessel (*converter*) is then tipped upon pivots, and the melted steel is run out into a ladle and then poured into moulds.

Less than half an hour is time enough to change these tons of cast iron into steel. The process is called the *Bessemer* process.

How is steel made from wrought iron?—In the old way of making steel, bars of wrought iron are packed in charcoal and the two are shut up together in air-tight boxes.

They are then made red hot and are kept so for several days.

During this heating, carbon finds its way into the solid iron and changes the whole mass to steel. It is known as *blistered steel*, because the bars on coming out of their hot bed are found to have a great many bubbles or blisters on their surface.

The steel is then melted and run into moulds.

This process is called *cementation*. The best steel is made in this way.

COPPER.

Tubal Cain, the great grandson of one whose name is written among the first pages of sacred history, was a skillful workman in many metals. Brass is among those named. But what is brass? The brass so common to-day consists of copper and zinc; that which was used by *Tubal Cain* was not exactly this. It was made of copper, tin, and a little of several other metals, such as iron and lead. It contained copper, however, and this is the point which interests us now, for it shows that copper was known and used several thousand years ago.

In what condition is copper found in nature?—Copper is sometimes found free in nature, but its compounds, or ores, are far more common.

Where is native copper found?—The free, metallic copper is found in the noted mines of Cornwall and Devon, in England, and in many other parts of Europe. But some of the finest native copper in the world is found in the region of Lake Superior. One single mass of Lake Superior copper weighed over 400 tons!

What is the appearance of native copper?—The native copper has very curious crystalline forms. In some cases it is found in little cubes. In some cases the little

crystals are grown together in vast numbers, and thus make large masses, and these masses often show the most singular branch-like shapes, (Fig. 58,) tempting one, sometimes to fancy that the metal had tried to imitate the form of some growing plant.

Fig. 58.

Name one of the ores of copper.—*Copper pyrites* is the most abundant ore of this metal. To a great deal of this ore nature has given the form of beautiful cubes, of a color and lustre something like brass, and often of the most perfect form. This ore is composed of copper, iron and oxygen.

Name another ore of copper.—*Malachite* is a rich ore of copper, but much less common than pyrites. It is a stone of most beautiful color. Its rich, green surface takes a fine polish, also, and on these accounts it is often used for purposes of ornament. It is a compound of copper, carbon and oxygen, with a little water.

Are there other ores of this metal?—There are many other ores of copper. Some are blue, some are red, some are purple, some are grey ; but we will not stop now to study them.

Nor will we try to learn all the details of the manufacture of the metal from these ores. The operations are quite numerous, and do not seem to be so simple as the smelting of iron.

Give a very brief description of the smelting of copper.—The ores are *roasted* and *melted* and then roasted again, and afterward remelted. These operations are repeated, until the mass is made to consist chiefly of two compounds of copper, one containing sulphur and the other oxygen.

This mass is again *roasted*, and this time these two compounds attack each other. One of them gives up its sulphur, the other gives up its oxygen, and so the copper of both is left free.

But the metal is not yet fit for the market. It must be *refined* to get rid of other metals which it holds in small but hurtful quantities.

The metal is refined by being melted over again, and kept fluid for many hours in contact with air. When the fire and

Fig. 69.

the air have burned out the impurities, the liquid copper is taken out in iron ladles lined with clay, and poured into moulds, and comes out of the moulds in the shape of bars such as seen represented in the picture.

What are some of the uses of copper?—Copper is used for a great many things in the arts. It is used for mak-

ing kettles, pans and boilers; for the sheathing of ships which carry our merchandise over the sea; and for telegraph wires, which transmit our thoughts over the land and under the ocean.

It is also used to mix with other metals in making substances called *alloys*.

Name some of these mixtures.—*Brass* is an alloy of copper and zinc; it is made by melting together two parts of copper to one of zinc.

Bronze, gun-metal and bell-metal are, for the most part, mixtures of copper and tin.

German silver is an alloy of copper, zinc and nickel.

ZINC.

The ores of zinc seem to have been known in very early times, but the metal itself was not. It was first noticed to be a metal by PARACELSUS about 350 years ago.

What are its most common ores?—Zinc is found combined with sulphur; this sulphide is called *blende*.

It is also found combined with oxygen; this oxide is called *red oxide*.

It is also found combined with oxygen and carbon; the name of this ore is *Smithsonite*.

Where are these ores found?—These ores of zinc, and others too, are met with in almost every country. One of the most remarkable of all their native places, is New Jersey,

How is the metal obtained from its ores?—Let the ores of zinc be heated in a current of air, or, in one word, *roasted*, and their sulphur or their carbon will be burned away. Now this is usually the first step toward getting zinc.

The *roasting* leaves the zinc with oxygen, and what is needed is that these two elements shall be separated. How shall this be done? Let carbon be mixed with the roasted

ore, and let both be put into a close iron vessel and heated in a furnace. As soon as the mixture is hot enough, the zinc and the carbon both struggle to hold the oxygen, but oxygen prefers the carbon; the two combine and fly away as a gas, and the zinc is left alone.

But when so hot the zinc is a vapor, and it too flies out of the iron vessel; it goes over into a colder one and there becomes a liquid. It is run into moulds and comes out in the shape of flat cakes, and is then sent into market.

What are some properties of zinc?—Zinc is a bluish white metal about seven times as heavy as water.

Zinc is usually quite brittle, but heat changes it, in this respect, very strangely. At common temperature it is brittle. At 212° and up to 300° it has lost its brittleness, and it may be hammered or rolled out into thin sheets, or pulled out into wire without breaking. But let the heat run up to 400°, and the metal is brittle again.

What are some uses of zinc?—Sheets of zinc are very common; we often see them under stoves to protect the floor. It is often used in making *galvanized iron*, which is sheet iron coated with zinc by plunging it into a hot bath of that metal. Zinc is also used as one metal in many useful alloys, as brass, bell metal, and German silver.

TIN.

Tin was known almost as as long ago as iron or copper. It was called *Jupiter* by the old alchemists, and *stan* by the people of Phœnicia. These people just named discovered tin in Britain more than a thousand years before the Christian era, and took much of it away from that island in ships.

Where is tin found?—The ore of tin is found in Cornwall, England, noted for its tin mines since many hundred years ago. Bohemia, Saxony, and Malacca and Banca, in India, also yield the ore of this metal. In this country it

seems to be very rare, but it has been found in New Hampshire and California.

In what form is tin found?—Tin is found in the form of *tinstone*. Tinstone is a compound of tin and oxygen. This is almost the only ore of the metal; how limited the distribution of tin compared with that of either iron or copper!

How is tin obtained from the ore?—The ore is passed through a most torturing set of operations to make it give up its metal. It is *stamped* to powder under wooden stampers shod with iron. It is *roasted* by a furnace fire. It is *washed* by violent stirring in a tank. It is *smelted* with coal and lime. And finally it is *refined* by melting it over again, and *cast* into large bars by being run into moulds made of granite or cast-iron.

What are some of the properties of tin?—The surface of common tin-ware shows the color of this metal; it is white and brilliant. This white surface is easily scratched because the metal is soft; it is harder than lead but softer than gold. Tin foil is tin (with a little lead) in the form of thin sheets, sometimes so thin that a thousand thicknesses would be no more than an inch; how very malleable tin must be!

Tin is tarnished slowly in the air, because oxygen does not easily combine with it. But this is not true when heat is applied; the surface then is soon darkened because *hot* oxygen attacks the *hot* metal quickly.

What are the uses of tin?—Because tin is so malleable it is much used for making tin foil. Because the air does not readily tarnish it, tin is used for coating iron to keep it from rusting, and other metals also, to protect their surface. And besides all this there are many useful alloys of tin.

What is common tin plate?—The "tin" of common ware is sheet iron covered with a thin coating of tin.

What alloys of tin are common?—Its alloys with copper have been named already. With lead it forms pewter and britannia metal, and the solder used by plumbers.

LEAD.

The lead ores of Spain and of England were worked by the ancient Romans, and still farther back, even to the times when the sacred books of Exodus and Job were written, this metal was known and used.

In what form does lead occur in the earth?—The ores of lead are many; but for the most part, they are not abundant. One of them, however, is found in immense beds and veins in the rocks. This ore is called *galena.* It is a compound of lead and sulphur.

Illinois, Iowa and Missouri, to say nothing of several other of our States, have an abundance of galena stored away in their rocks.

How is the metal obtained?—To obtain the metal the ore is *roasted* on the floor of a furnace with plenty of air. The hot oxygen changes a part of the sulphide into compounds containing oxygen. The furnace is then shut tight and the fire driven to a greater heat. The new compounds just mentioned then attack and decompose each other and give up their metallic lead.

What are some of the properties of lead?—The color of this metal and its softness are known to all, and need not be described to you; its weight also is known to be great; it is well to learn that it is almost eleven and a half (11.4) times as heavy as water.

The surface of lead is always tarnished, except for a few minutes after being freshly cut. In perfectly dry air it remains bright, and this shows that moisture is needed to give the tarnish. In water with no air in it the metal also stays bright, and this shows that air is also needed to tarnish it. Both air and moisture, then, are needed.

What is its effect upon the system?—This metal, when taken into our bodies, unites with the tissues and re-

mains. If more be taken, the quantity which stays in the body is increased, until finally there is enough to act as a deadly poison.

What are some of the uses of lead?—It is quite malleable and can be rolled into sheets, which are used for lining vessels for water and other liquids. It is also made into pipes for water and gas. Shot and bullets are made of this metal.

What is its most useful alloy?—Lead, with tin and antimony, are melted together to make *type-metal*, the most useful of all alloys, since the art of printing depends upon its use. It has the curious property of expanding, when it cools, from the melted liquid form to a solid. On this account when poured into the type-moulds and allowed to become cold, it fills every little groove and marking of the mould, and thus takes the perfect shape of the type.

MERCURY.

The name of the planet Mercury was once given to all volatile substances, but that was long ago, and the name now clings to only one, *a liquid metal.*

This metal was known in very ancient times, and besides *mercury*, the old chemists gave it a name which means *quicksilver*, by which they knew it and which we still use. Its more dignified name was the long and clumsy *hydrargyrum.*

Where is mercury found?—This metal is found in California, in China, in Austria, and in other countries to some extent. Perhaps the most noted among its native countries is Spain; the mines of Almaden have long been worked and have yielded a rich reward.

In what condition is mercury found?—Mercury is generally found combined with sulphur. This ore is called *cinnabar.* It is a very pretty mineral, much the color of

cochineal. Sometimes this ore is so pure that its color is as rich and brilliant as that of *vermilion*. Indeed, these two things have the same composition; cinnabar is the sulphide which is found in the earth; vermilion is that which is made in the chemist's laboratory.

Is mercury found free in the earth?—Sometimes the liquid metal is found in cavities of its ore, ready to run out if an opening is made. How easy to get a metal to be found in this condition! But, unfortunately, this native mercury is not common, and the metal must be obtained from its ore.

How is mercury obtained?—Even then the process is much more simple than those for such other metals as iron and copper.

The ore is *roasted* in a furnace with plenty of air. The oxygen of the air attacks the cinnabar, seizes its sulphur and flies away with it in the form of sulphurous oxide. This leaves the metal free but in the form of vapor. This hot vapor is passed off through long channels into a cold chamber where it is cooled down into a liquid form.

What are some properties of the metal?—At ordinary temperature this metal is a liquid about 13½ times heavier than water. But when cooled down to 40° below zero it is frozen into a silver-white solid, or when heated to about 660° it boils away into a colorless vapor.

It combines very readily with chlorine and with sulphur; not so easily with other elements.

What are its compounds with chlorine?—With chlorine, mercury forms two notorious compounds. One of these, *corrosive sublimate*, is a most violent poison; the other, *calomel*, is a medicine in extensive use. Calomel contains less chlorine in proportion to the mercury than corrosive sublimate.

What are some of the uses of mercury?—This liquid metal is much used in making thermometers and barometers.

Another important use of mercury is in operations of taking gold and silver from their ores.

What are amalgams?—Mercury combines with other metals and forms what are called *amalgams*. The most familiar example of an amalgam is to be found on the backs of looking glasses; this substance is a compound of mercury and tin.

SILVER.

We are told that Abraham was very rich, and we are also told that his riches consisted of cattle, and *silver*, and gold. Now Abraham lived no less than two thousand years before the Christian era. We see then that even in such ancient times silver was known and was valued as a precious metal, In the days of King Solomon it must have been very plenty. for we read that this metal "was nothing accounted of" in his day; that, indeed, he made silver to be as stones in Jerusalem.

In what condition is silver found in the earth?—Silver is sometimes found native. Such specimens are often very beautiful, looking like metallic twigs and branches.

There are several ores of this metal, but none is more common than the *sulphide*, that is, the compound of silver and sulphur. In its pure form it contains about 87 pounds of silver in every 100 pounds of ore; but it is not often found so rich as this in mines, because it is mixed with the sulphides of other metals, such as copper and lead.

Silver is almost always the precious companion with lead in galena, and much silver is obtained from that ore. It is said that if there be no more than *two* parts of silver in a *thousand* of galena, the precious metal can be profitably obtained.

How is silver obtained from its ores?—There are different ways of taking silver from its ores; we cannot

try to learn them all now. Freiberg, in Saxony, is noted for its treatment of silver ore. Let us very briefly notice the operation as it is conducted there. The ore is chiefly the impure sulphide.

What is the first step?—The ore is well stamped in a mill to crush it to powder, and then mixed with a little—about one tenth of its weight—common salt. The mixture is then *roasted*, first at a low heat, then at a high heat, and, to make sure that the work is well done, the roasted ore is mixed with more salt and roasted over again. In this way chlorine is made to take the place of the sulphur in combination with the silver. The next object is to get rid of the chlorine.

How can the chloride be decomposed?—The fine powder is put into strong oaken casks with water and fragments of iron. By turning these casks rapidly the mixture within is violently shaken, and under this treatment the iron robs the silver of its chlorine. The silver is thus left free, but it is in very fine particles scattered through the mixture in the casks.

How shall it be collected?—Just at this point the use of mercury comes in. Mercury is poured into the casks, which are then set rotating again faster than before. In this way the mercury is made to dissolve the silver, and an amalgam is thus formed. How can the silver be taken out of this amalgam? The amalgam is put into iron dishes and strongly heated. The mercury goes away in vapor and the silver is left behind.

Is the silver thus obtained pure?—It is not pure. It contains other metals, such such as copper, zinc and antimony, mixed with it. These must be removed, and so the metal is melted with a portion of lead in a current of air. The oxygen seizes the lead and other impurities, and leaves the silver pure.

What are some of the properties of silver?—Silver

is the whitest of metals. It is ten and a half times as heavy as water. It is much harder than gold, and very malleable and ductile.

Oxygen does not attack it even when hot; but its surface will quickly blacken in the presence of sulphuretted hydrogen, because silver and sulphur strongly attract each other.

What are some of the uses of silver?—Articles of silver ware and silver coin are well known. But we must remember that none of these are made of pure silver. The pure metal is quite too soft to be able to stand the wear which these things receive. To harden the silver, small portions of other metals are mixed with it.

What is coin metal?—For silver coin some copper is added to harden the precious metal. In this country the standard coin metal is made of silver 90 parts and copper 10 parts. In England the proportion of copper is less (7.5,) in Germany it is more (12.5.)

GOLD.

We have no history of the time when gold was not known. The oldest records speak of this most precious metal as among the richest articles of wealth and of ornament.

Where is gold found?—There are few countries in which the earth does not contain some gold, but there are few in which the quantity of this precious metal will reward the labor of separating it from the earthy and stony bodies with which it is found. "The sands of the Siberian rivers are not considered to be worth washing if they contain less than one part of gold in a million." The mines of South America gave the world most of the gold it received until very recent times. But the larger part now comes from the rich deposits of California and Australia.

In what condition is gold found in nature?—Gold is

always found native. As if too noble to join itself to baser substance, this precious metal is never known in nature to be *combined* with other elements. Yet this native gold is not pure; it is mixed with a little silver and sometimes, too, with copper. This native gold, in fine grains, is found among the sands of certain rivers, and also scattered here and there in hard quartz rock, and now and then a *nugget* of considerable weight rewards the miner.

How is gold separated from sand or other loose material in which the dust is found?—Sometimes the loose material is put into a shallow pan and well stirred up with water. Gold is so heavy that the grains will quickly settle to the bottom and the earthy matter may be poured off from above it. This operation is called "washing." Sometimes the gold-bearing deposit is washed by rocking it in a cradle through which a stream of water is slowly running. The lighter earth or sand is then washed away while the heavy *gold dust* lags behind and is caught in grooves across the bottom of the cradle. The precious metal is then dissolved in mercury and afterward separated by heat.

How is gold obtained from quartz rock?—When the gold is found in the quartz rocks they are crushed to the finest powder and then mixed with mercury. The mercury dissolves the gold and leaves the quartz unharmed. The amalgam of gold is then distilled and the mercury goes away as vapor while the gold is left behind alone.

What are some properties of gold?—Gold is remarkable for its fine yellow color and beautiful lustre. It is among the heaviest of metals, about 19 times (19.33) heavier than water. It is the most malleable of metals; it is said that leaves have been beaten so thin that 280,000 would be needed to make an inch in thickness! There is a curious fact about the color of gold leaf; it is this: looked at in the usual way it is yellow, but let a leaf be spread upon glass so

that it may be held up between the eye and a window, or the sky, and it will be green.

What is the effect of heat upon it?—At a temperature of about 2000° F. (2016) this precious metal melts into a greenish colored liquid. The highest heat of a furnace can scarcely change it into vapor, but the furious flame of the oxyhydrogen blowpipe can; its vapor has a purple hue.

Is it affected by chemicals?—Few chemicals, even of the most corrosive character, can harm this noble metal. Oxygen cannot rust it like iron; sulphur cannot tarnish it like silver; nor can the strongest acids corrode it. For one element, however, it has a strong attraction; it is chlorine. *Aqua-regia* is made by mixing nitric acid and hydrochloric acid together, and it contains chlorine. Its name means *royal water;* why is it so called? Because it will dissolve "the king of metals,"—gold. Bromine and Iodine, so much like chlorine in other respects, are also able to act upon gold.

What are some of the uses of gold?—Gold is used for ornament and as money. But when pure it is almost as soft as lead, and hence unfit for either use. To make it harder a little copper or silver is added. The alloy used for coin in this country must be made of *nine* parts of gold to *one* part of copper.

FARADAY.

CHEMICAL ATTRACTION.

Describe the experiment with an explosive soap-bubble.—Let a solution of soap be made, such as we have often used for blowing bubbles, but instead of blowing them with our lips let us fasten the pipe to a tube leading from a bottle in which hydrogen gas is being set free. Then if the bubble pipe be dipped into the soap solution the bubble will be blown out with hydrogen gas. Very soon it will break away and fly upward like a pretty little balloon. Now if another person will hold a lighted taper above, so that the bubble will touch the flame on its way up, it will explode with a sound quite startling.

What is the substance which explodes?—It would seem at first that there could be nothing but hydrogen in the bubble, but there is something more. Air goes into the bubble, through the pores of the thin film of soap-water, so

that there is a *mixture* of *hydrogen and air* inside. It is this mixture that explodes.

Does the nitrogen of the air take any part in making the sound?—But we know that nitrogen does not help to make the explosion; indeed it hinders the work very much. If the oxygen were alone to mix with the hydrogen the sound would be many times louder.

What is produced by the action?—There is a new substance made in this explosion. It is water. The hydrogen and the oxygen are both used up, and water takes their place.

For this reason we say that water is a *compound* of hydrogen and oxygen.

What causes these two elements to combine?—When oxygen and hydrogen are mixed together, think how the molecules of one must be scattered among those of the other. How close together they must be! And yet the chemist tells us that he thinks that if we could only see these molecules we should find them to be some distance apart. As long as they stay apart there is no explosion, but when the hydrogen and the oxygen molecules *fall together* they do so with a loud sound, and then they stay together in the form of water.

But what causes them to fall together?—They would not fall of their own accord any more than a stone will fall to the ground of its own accord. The stone falls *because it is pulled down* by the force of gravitation. The molecules of hydrogen and of oxygen fall together because they are pulled together by the force of *chemical attraction.*

What happens to the molecules when they fall together?—When a stone falls to the ground it is sometimes broken into pieces. Now the chemist thinks that when the molecules fall together they, too, are shattered, and the little pieces into which they are broken he calls *atoms.* These atoms of hydrogen and oxygen are then held firmly together by chemical attraction and form water.

What then is chemical attraction?—We may now define chemical attraction. *It is the force which brings atoms of different kinds of matter together and then holds them together in a compound.*

All compounds are formed by the action of chemical attraction. Every chemical change that ever occurs is brought about by this kind of attraction. It causes the rusting of iron, the decay of wood, the combustion of coal, the explosion of gunpowder, the ripening of fruit, and so many other effects that it will be useless for us to try to name them. Yet it does not act at random; not a single one of its effects comes by chance or accident. Let us study its action and learn something of the laws which govern it.

Fig. 61.

What proportions of hydrogen and oxygen are needed to form water?—When electricity is passed through water (see Fig. 61) its two gases are separated and may be caught

in different tubes. We see in this experiment that the hydrogen tube is filled twice as fast as the oxygen tube. This shows that water contains twice as much hydrogen as it does oxygen. If we get two cubic inches of hydrogen we can get at the same time only one cubic inch of oxygen.

What if we weigh the gases?—If we weigh the gases which we may get from water, we find that the oxygen weighs *eight* times as much as the hydrogen. If we get *one* ounce of hydrogen from water we get at the same time *eight* ounces of oxygen; or if we get five grains of hydrogen we get at the same time forty grains of oxygen.

Is water always made up of these proportions of its elements?—Water is always made up of exactly these proportions of hydrogen and oxygen. It may be analyzed in many ways, but it gives, by every way, just eight times as much oxygen as hydrogen.

What law does this illustrate?—*Every compound is always made up of the same elements, and always of the same proportions of the elements by weight.*

This is the "first law of chemical attraction."

How is this law illustrated by hydrochloric acid?—Hydrochloric acid is *always* made up of the two elements hydrogen and chlorine, and the chlorine always weighs just 35.5 times as much as the hydrogen.

How is the law illustrated by common salt?—Common table salt is made up of the two elements, sodium and chlorine, and the weights of these elements in it are as 23 to 35.5. If for example, there are 23 ounces of sodium in a quantity of salt there will be 35.5 ounces of chlorine in the same quantity. Or if the sodium is *twice* 23, then the weight of chlorine will be twice 35.5. Salt is always made up of these same elements and always in these same proportions.

What is a molecule?—One of the first things we learn

in studying natural philosophy is that every body of matter is made up of molecules, and that a molecule is *a particle of matter so small that it cannot be divided without changing its nature.* A molecule of hydrochloric acid, for example, is a particle of that substance which cannot be divided without changing it into some other kind of matter different from hydrochloric acid.

Can the molecule of hydrochloric acid be divided at all?—But a molecule of hydrochloric acid contains an atom of hydrogen and an atom of chlorine, and it can be broken into these two pieces.

How can this be done?—Let us try an experiment. Into an ale glass we will put a little hydrochloric acid, and then we will drop into it a few small pieces of zinc. What a curious action begins! What a boiling and a foaming! Let us bring a lighted match over the mouth of the ale glass. A loud explosion is heard and a dull red flame instantly begins to play over the surface of the foaming liquid. Now the explosion and the flame shows us that hydrogen is being set free.

What is happening in the glass?—We see the violent boiling of the liquid and the dull red flame, but our eyes are not keen enough to see the cause of all this. The chemist tells us that the zinc is *breaking the molecules* of the acid into pieces, and that this causes the violent commotion in the glass. Let us repeat his story a little more accurately. By chemical attraction the zinc pulls the atom of chlorine out of each molecule of the acid and lets the atom of hydrogen go free. The hydrogen, from a host of these broken molecules, makes a bubble of the gas and these bubbles of hydrogen rise to the surface where they go off into the air, or may be burned.

How much of each gas in one molecule of the acid?—We have learned that this acid contains 35.5 times as much chlorine as hydrogen; we may say this of any

quantity ; it is true of one molecule. We have no idea of how much, or rather how little, the atom of hydrogen really weighs, but we do know that whatever it does weigh, the atom of chlorine weighs 35.5 times as much. We cannot tell the weight of either in fractions of a grain or ounce, but we can call the weight of the hydrogen atom ONE, without saying what, and then we can say that an atom of chlorine weighs 35.5.

What do these numbers represent?—Now these numbers represent the smallest proportions by weight of hydrogen and chlorine which ever combine with each other.

Thus if we take one ounce of hydrogen we must take no less than 35·5 ounces of chlorine to combine with it. A pound of hydrogen will take just 35,5 pounds of chlorine. No human power can make it take either more or less.

What are these numbers called?—These numbers are called the combining weights of hydrogen and chlorine, because they represent the smallest proportions by weight in which these gases combine.

Do other elements have combining weights?—Every other element has a number wh[illegible]h shows the smallest proportion of it which can enter into a compound. When we compare hydrogen and oxygen we find that the smallest weight of oxygen is 16 times as heavy as that of hydrogen. And so we say that the combining weight of oxygen is 16.

If we compare hydrogen and nitrogen we find that the smallest proportion of nitrogen is just 14 times heavier than that of hydrogen. So we say that 14 is the combining weight of nitrogen. In the same way each element has a number which we call its combining weight.

Define combining weights.—Combining weights are the numbers which show the smallest relative proportion by weight in which substances combine.

Can two elements make more than one compound?

—Two elements may form more than one compound. Carbon and oxygen do this. They give us carbonic dioxide, a gas, you remember, which will not burn and which will extinguish fire, like water. But they also give us another gas which burns with a fine blue flame, the flame which you may have seen playing over a newly made coal fire.

How can the same elements give more than one compound?—The only difference in the composition of the two gases just spoken of is in the quantity of the oxygen they contain. There is twice as large a proportion of oxygen in carbonic dioxide as in the other. So, by combining in different proportions, two elements may form more than one compound.

How many compounds do nitrogen and oxygen form?—Nitrogen and oxygen produce no less than five different compounds. Let us examine some of these to see how very different in character may be the substances made of exactly the same elements. One of these compounds is called *nitrous oxide.*

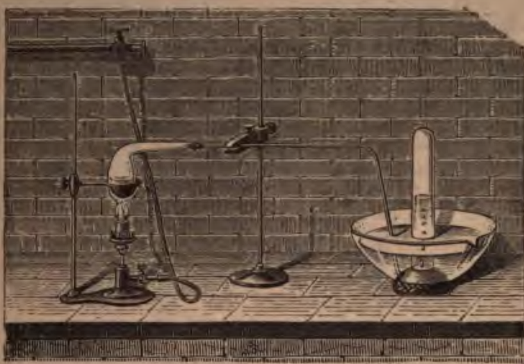
How may nitrous oxide be obtained?—Nitrous oxide may be obtained by heating a compound called ammonic nitrate. The picture shows how the operation may be conducted.

The ammonic nitrate is put into a retort (the name given to such a vessel as you see at the left in the cut) and heated by a lamp or furnace. The heat first melts it to a limped fluid and then decomposes it. What new things are formed? Steam is one and nitrous oxide is the other. It will be easy to trace these through the apparatus. You see that they must pass in a bent tube over to and through cold water in the basin, where, of course, the steam is left behind. Then the oxide bubbles up to be caught in the inverted glass jar.

What are some of its properties?—The jar is then seen to be full of a colorless gas. It is not only colorless,

but almost without odor also. It is very much heavier (1.52) than air, and quite readily dissolved by cold water.

Fig. 62.



What is its effect upon flame?—Plunge a lighted taper into nitrous oxide, and it will burn with almost as much vigor as it would in oxygen.

What is its effect when breathed?—It may be breathed instead of air for a short time without danger, but its effect is very curious. The person usually seems to become very happy, and sometimes bursts into laughter. On this account this gas is often called "laughing gas." The effect soon passes off.

When the pure gas is breathed for a little time the person is made insensible. He may be pricked with a pin or cut with a knife without knowing it. On this account surgeons sometimes make their patients breathe this gas, in order that the pain otherwise caused by their operations may not be felt.

What proportions of nitrogen and oxygen in this gas?—This gas contains 28 parts of nitrogen to 16 of oxygen. If its nitrogen weighs 28 grains, its oxygen will weigh

16 grains. If its nitrogen weighs twice 28, or 56 grains, then its oxygen will weigh twice 16, or 32 grains.

Now let us examine another compound of these elements having different proportions ; we shall find it to have a different character too. It is called *nitric oxide.*

How may nitric oxide be obtained?—It is obtained by putting copper and nitric acid together. Look at Fig. 63. You see that the apparatus is the same as is used in getting hydrogen gas.

Fig. 63.

Some clippings of copper are put into the bottle. Afterward some nitric acid is poured in upon the copper through the funnel tube. A violent boiling begins at once and a curious change in color is made. The liquid inside the bottle becomes *green ;* the air above the liquid becomes *red ;* but the gas that bubbles into the jar in the cistern is colorless. This colorless gas is the nitric oxide.

What are its properties?—It is without color, but it has a strong odor and cannot be breathed without causing suffocation.

What is its effect upon flame?—Plunge a lighted

taper into it and the flame expires. Even phosphorus will be extinguished unless it is burning very briskly when plunged into this gas.

What is its most remarkable action?—It has very strong attraction for oxygen, and we only need to let a little out of the jar into the air to show it. A cloud of cherry-red vapor instantly appears. This red substance is produced by the union of nitric oxide with the oxygen which it meets in the air.

What proportions of nitrogen and oxygen in this gas?—This gas contains 14 parts by weight of nitrogen to 16 parts of oxygen. If its nitrogen weighs 14 grs. its oxygen will weigh 16 grs. If its nitrogen weighs twice 14, or 28 grs., then its oxygen will weigh twice 16, or 32 grs.

The only difference in the composition of these two gases is that the nitric oxide contains less nitrogen than the nitrous oxide. But what a difference in character this simple difference in composition produces!

Are there other compounds of these elements?—There are three others. One of these is an orange-red gas, which, when made very cold, becomes a blue liquid. Another, is the dark cherry-red gas which is made when nitric oxide is let out into the air; and the third is a colorless solid, which dissolves in water and forms the powerful nitric acid so useful in the arts.

What is the difference in these compounds?—The only difference in the composition of these three things is in the *proportions* of the nitrogen and oxgen they contain. This simple difference causes all the difference in their properties.

How may their difference in composition be best shown?—By writing the numbers representing the weights of nitrogen and oxygen in a table, we can easily see this difference. Thus.

Nitrous oxide	contains	28	of	nitrogen	and	16	of	oxygen.
Nitric oxide	"	14	"	"	"	16	"	"
Nitrous anhydride	"	28	"	"	"	48	"	"
Nitric peroxide	"	14	"	"	"	32	"	"
Nitric anhydride	"	28	"	"	"	80	"	"

You may call these numbers so many grains, or ounces, or whatever weight you please. No matter how much of either of the compounds is examined, the weights of the nitrogen and oxygen will have the ratio shown by the *numbers in table*, opposite the name of the compound.

What curious fact is seen when we examine the quantities of oxygen shown in the table?—We see that in the first compound the quantity of oxygen is 16, but 16 is the combining weight of oxygen. In the second compound the oxygen is also the combining weight. In the third the quantity is just *three* times the combining weight. In the fourth it is just *two* times the combining weight; and in the fifth it is just *five* times the combining weight. Every one of these proportions of oxygen can be divided by the combining weight without any remainder.

Is the same thing true of the nitrogen?—The same thing is true of the nitrogen. Notice: its combining weight is 14, and there is no number for nitrogen in the table which 14 may not divide without a remainder.

Is this true in other cases?—There are a great many examples in chemistry of several compounds made up of the same elements; but what we have seen to be true for the nitrogen and oxygen is true in every such case.

How may the principle be stated?—*If one substance combines with another in more than one proportion, these proportions are always multiples of its combining weight.*

This principle is called " the second law of combination;" it should be understood and remembered.

Now let us study the following table of elements :

Oxygen,	16	O.
Hydrogen,	1	H.
Nitrogen,	14	N.
Carbon,	12	C.
Silicon,	28	Si.
Chlorine,	35.5	Cl.
Bromine,	80	Br.
Iodine,	127	I.
Sulphur,	32	S.
Phosphorus,	31	P.
Arsenic,	75	As.
Iron,	56	Fe.
Aluminum,	27.4	Al.
Calcium,	40	Ca.
Magnesium,	24	Mg.
Sodium,	23	Na.
Potassium,	39.1	K.
Copper,	63.5	Cu.
Zinc,	65	Zn.
Tin,	118	Sn.
Lead,	207	Pb.
Mercury,	200	Hg.
Silver,	108	Ag
Gold,	196.6	Au.

This table includes all the most common and important elements. In the first column we see their names.

What do we see in the second column?—In the second column we find a number opposite the name of each element. These numbers are the *combining weights* of the elements. The combining weight of silver, for example, is 108, as you will notice, and then you must remember that this means that the smallest weight of silver that can combine with any other element is 108 times greater than the smallest weight of hydrogen that can combine.

What do we see in third column?—In the third column we see what the chemist calls the symbols of the ele-

ments. He uses these letters often instead of the names. Thus, instead of writing the name OXYGEN out in full, he often saves time and work by just writing the first letter of the name—just O. For the long name POTASSIUM he often writes K, the first letter of its Latin name, kalium.

Whenever we see O, in chemistry, we know that it means oxygen, and when we see K, we know that potassium is meant. P stands for phosphorus. The latin name for copper is cuprum, and its first letters, Cu, are the symbol for copper.

What do these symbols represent besides the names of the elements?—Besides the name of the element each symbol represents a number, the combining weight of the element. Thus: O means not only oxygen, it means 16 also. Cu stands for copper and also for the combining weight of copper, 63.5.

Now look in the table and say what two things are meant, in chemistry, by the symbol Au.

Look again for the meanings of Fe; and again for C; and for I.

How are these symbols used to show the composition of compounds?—Let us take an example: we want to show the composition of water. We know that it is composed of two parts of hydrogen to one part of oxygen, and this is what we want to show by symbols. We will write H_2O and it is done. The H shows the presence of hydrogen and the little figure 2 shows that there are two combining weights of it, and the O shows that there is one combining weight of oxygen.

Give another example.—HNO_3 shows the composition of nitric acid. H means one combining weight (1) of hydrogen. N means one combining weight (14) of nitrogen, and O_3 means three combining weights (3×16) of oxygen. Hence nitric acid is composed of hydrogen, nitrogen and oxygen in proportions of 1, 14 and 48; so that if we should

have sixty-three pounds of the acid, there would be one pound of hydrogen, fourteen pounds of nitrogen and forty-eight pounds of oxygen in it.

The composition of carbonic dioxide is represented by CO_2. Can you, by looking at the table of elements, tell what are the names of its constituents and the proportions of each?

Tell us, then, how to show the composition of a compound by symbols.—*Write the symbols of its elements one after another, and if there is more than one combining weight of any element, put a small figure just a little below and to the right of its symbol.*

Now turn back to the table which tells you the composition of the compounds of nitrogen and oxygen, and see if you can show the composition of each one by symbols. You see that nitrous oxide contains 28 of nitrogen—that is, two times the combining weight. You show this by just writing N_2. You see that the substance contains just once the combining weight of oxygen; you show this by writing just O. Then put these symbols together, thus, N_2O, and the work is done. Do this for the four other substances yourself, for practice.

But this is not the only use the chemist makes of these symbols; he uses them to explain chemical actions. You see already that the composition of any compound that has ever been analyzed may be shown by symbols; notice next that every chemical change that takes place may be written out in symbols. Let us make an experiment and study it by symbols.

Describe the experiment.—Let us put a few clippings of zinc into an ale glass, and then pour some dilute sulphuric acid upon them. Instantly the fluid begins to foam violently, and if we bring the flame of a match over the mouth of the glass we hear a dull explosion and see that hydrogen is escaping.

How can the change be shown by symbols?—Now Zn (zinc) and H_2SO_4 (sulphuric acid) are the things put into the ale glass; we will write them together thus, $Zn + H_2SO_4$.

We know that H (hydrogen) is set free, for it is that which burns; the zinc is left with the SO_4; thus, $ZnSO_4 + H_2$.

Hence,
$$\underset{\text{Before the action.}}{Zn + H_2SO_4} = \underset{\text{After the action.}}{ZnSO_4 + H_2}.$$

What does this equation mean?—This equation shows that the zinc takes the place of the hydrogen in the acid and forms a new compound, while the hydrogen is set free.

Describe the experiment with potassium?—Let a piece of potassium as large as a small pea be dropped into a glass vessel containing some hydrochloric acid. The metal will float upon the liquid, melt into a globule, burst into flame and run briskly over the surface from side to side until it is exhausted.

What equation shows the chemical changes in this experiment?—The substances used and the new ones formed stand thus:

$$K + HCl = KCl + H.$$

What does this show?—A little study will help you to see that the potassium (K) takes the place of the hydrogen in the acid, (HCl,) and by so doing makes a new compound (KCl) and sets the hydrogen free.

In this way symbols are a most valuable kind of shorthand writing in chemistry, saving much time and work, and at the same time showing more clearly at a glance, the chemical changes, than words could do.

Describe the experiment with vinegar.—Let a little solution of blue litmus be added to an ale glass of water;

the water takes a deep blue color. Next add a few drops of strong vinegar, and notice a curious change in color. The blue is changed to red.

Describe another similar experiment.—Let the water of another goblet or ale glass be colored blue by litmus, and then put in a drop or two of sulphuric acid. Red clouds appear in the blue liquid, and if shaken or stirred, the blue disappears and the liquid is red throughout.

What other substances will cause this change of color?—A few drops of nitric acid will redden a large vessel of blue litmus water. The same change will also occur if hydrochloric acid be used. Many other substances, which we will not stop to name, would have the same effect.

What do we learn from these experiments?—We see that there is *a class* of substances which are able to redden the color of blue litmus. These substances are called *acids.*

What is the taste of an acid?—The sour taste of vinegar is well known. Sulphuric acid has the sour taste in a greater degree; it is intensely sour. Nitric acid, hydrochloric acid and, in a word, *all acids are sour to the taste.*

What element is always found in acids?—The following table shows the composition of several acids, by symbols:

Nitric acid,	HNO_3	Hydrochloric acid, HCl.
Sulphuric acid,	H_2SO_4	Hydroiodic acid, HI.
Phosphoric acid,	H_3PO_4	Hydrobromic acid, HBr.,

and a glance at these symbols shows that hydrogen (H) is a constituent in every one. *Every acid contains hydrogen.*

In what three respects are acids alike?—In the first place we saw that an acid will redden blue litmus.

In the second place we found that an acid is sour to the taste.

In the third place we noticed that an acid always contains hydrogen.

Any substance having these qualities is an acid.

What difference in the composition of acids to be seen in the table?—Look at the two sets of symbols in the table just passed. In each acid of the first column, oxygen (O) is present; it is not to be found in those of the second.

Now we may learn from this that there are two classes of acids. One class contains the element oxygen, the other does not.

What is the action of sodium on hydrochloric acid?—Try the experiment. Let a little ball of sodium be dropped into an ale glass containing the acid. A violent action begins, very much as when sodium is placed upon water. The metal melts, floats on the acid, runs from place to place, finding no rest, and finally disappears.

What chemical change has happened? Let us write the symbols:

$$\text{Na} \quad + \quad \text{HCl} \quad = \quad \text{NaCl} + \text{H}.$$

Sodium *and* acid *yield* salt *and* hydrogen.

This equation shows us that the sodium (Na) has driven the hydrogen (H) out of the acid (HCl) and taken its place. Two new things are thus obtained: salt (common salt) is produced and hydrogen gas escapes.

What is the point to be carefully noticed?—We should be careful to notice that the metal puts itself in the place of the hydrogen of the acid.

Would this happen if other acids were used?—It would make no difference in the action if we use any other acid in the list. The sodium would drive hydrogen out and put itself in the place of it.

Would other metals do the same thing?—Many other metals have the same power to act upon acids. Not every metal can do this to every acid, but the power to put

itself in the place of hydrogen in acids is very common among the metals.

What name is given to the new compounds formed by this action?—The new compounds formed by this action of the metals are called salts. When sodium and hydrochloric acid are used, the new compound, as we have seen, is common salt; you have only to evaporate the liquid to get the familiar white solid. Every acid would yield a different kind of salt with sodium. Each different metal also yields a different salt with every acid on which it acts.

What is a salt?—A salt is *a compound formed by putting a metal in the place of hydrogen in an acid.*

How may reddened litmus be made blue again?—A curious experiment is made by taking some blue litmus in an ale glass, turning it red by adding a few drops of acid, and then dropping a bit of potassium upon its surface. The metal acts in its usual way, taking fire, running around, wasting away, and finally going off in an explosion. But besides all these things another happens. The litmus solution is no longer red; it is blue again.

What new substance is formed in this action?—The action is between the water of the solution and the potassium. Let us write the symbols and represent the change:

$$K + HHO = HKO + H.$$

You can see here that the metal (K) has put itself in the place of one of the parts of hydrogen in water, (HHO,) and that by doing so it has formed the new substance (HKO) and set the hydrogen free.

Now this new substance (HKO) is the one which turns the color of the reddened litmus blue. Its common name is potash or potassa.

What other substances will do the same thing?—Try the experiment with ammonia. A few drops added to a

red solution of litmus will restore its original fine blue color. Besides potash and ammonia, there are many other substances which have this power to restore the blue color of litmus which has been turned red by an acid.

What do we learn from these things ?—Hence we see that there is *a class* of substances which are able to restore the blue color of reddened litmus.

What is the taste of these bodies ?—The well known taste of soda and potash is the characteristic taste of this class of bodies. It is the same as that of wood ashes ; indeed the peculiar "caustic" taste of wood ashes is due to the presence of potassa.

What is this class of compounds called ?—These substances which have a caustic taste, and the power to neutralize the acids, in litmus and other things, are called *bases* or *hydrates.*

What other class of compounds to be noticed ?—Water is a good example of bodies which are neither acids nor bases nor salts. It will not change the color of litmus, either to red or blue. It is not sour to the taste like the acids, nor caustic like the bases, nor is it made by putting a metal in the place of hydrogen in the acids as the salts are. There are a great many other compounds like water in these respects. They are called *neutral bodies.*

What do the names of chemical compounds show ?—In naming the compounds in chemistry the chemist does not invent names just to suit his fancy, but he tries to make them *show the composition of the compounds to which he gives them.*

How is this illustrated in the name of the compound of hydrogen and chlorine ?—Hydrogen unites with chlorine to form an acid ; it is called *hydrochloric* acid. Who does not see that the names of both the elements are suggested by

the name of the compound? *Hydro* makes us think of hydrogen, and *chloric* is something like chlorine, and so *hydrochloric acid* must be an acid which is made up of hydrogen and chlorine.

Of what is hydrobromic acid composed?—The word hydrobromic suggests hydrogen and bromine; these are the elements of which the acid is composed.

What are the elements in sulphuric acid?—Sulphuric acid is made up of sulphur, oxygen and hydrogen; its name is so made that the presence of these three things is shown.

What in the name shows the presence of these elements?—We have learned that *all acids* contain hydrogen. If a substance be called an acid that name alone is enough to make us know that hydrogen is one constituent.

The *ic*, at the end of the word sulphuric, is one of the signs which chemists have agreed to use to show the presence of oxygen.

The other part, *sulphur*, of the word sulphuric, shows the presence of sulphur.

What are the elements in sulphurous acid?—In this name the word *acid* shows the presence of hydrogen; the *ous* shows the presence of oxygen, while the name of sulphur is very distinct. Hydrogen, oxygen and sulphur are the elements of this acid.

What should be noticed in the two names just explained?—It will be seen that sulphuric acid and sulphurous acid are made of the same elements. The first contains a larger proportion of oxygen than the other, and this is their only difference in composition. Now *ic* is used in the name of the one that contains *the larger proportion*, and *ous* in the name of the other.

What is the composition of phosphoric and phosphorous acids?—These names differ in nothing except that one has the *ic* and the other has the *ous*; the first contains a *larger proportion of oxygen* than the second. The elements

are the same in both. They are phosphorus, indicated in the name by *phosphor;* oxygen, shown by *ic* and *ous;* hydrogen, by the word acid.

Now see if you can answer the following questions: What are the elements in chloric acid? What are the elements in chlorous acid? Of what elements is carbonic acid composed? Name the elements in nitric acid, and in nitrous acid.

What is the meaning of the prefix hypo?—There is an acid called hyponitrous acid. You may notice that the name nitrous acid here has the prefix *hypo.* This prefix is used to show that this acid contains a less *proportion of oxygen* than nitrous acid contains. Hypo is often used in this way. On the other hand, the prefix *per* is used to denote a larger proportion of oxygen. An example will make this clear. Thus, *perchloric acid* is an acid which has a larger proportion of oxygen in it than the *chloric acid* has, and the prefix *per* shows it.

Thus the names of acids show us the names of the elements which they contain.

Now let us see how the names of salts do the same thing.

We will not forget that a salt is formed by putting a *metal* in place of the *hydrogen* in an *acid.* The name of the salt tells us the name of the metal and of the acid from which it has been made.

What salt is made by sodium and sulphuric acid?—When sulphuric acid is used the salt is called *sulphate,* no matter what metal be employed. If sodium is the metal used, then the new salt found will be called *sodic sulphate.* It is easy to see that this name suggests the name of the metal and also of the acid.

But let us study the subject further.

What salts may be formed with sulphurous acid?

—Sulphurous acid forms a class of salts called *sulphites.* Notice the difference : sulphuric acid gives sulphates ; sulphurous acid gives *sulphites.*

What is the principle in this difference ?—The truth is, that if the name of the acid ends in *ic*, the names of its salts end in *ate.* But if the name of the acid ends in *ous*, the name of its salts end in *ite.*

Mention illustrations of this principle ?—A salt formed by chloric acid is called a *chlorate ;* but one formed by chlorous acid is called a *chlorite.* Nitric acid yields *nitrates*, but nitrous acid yields *nitrites.*

Different metals form different nitrates by acting upon nitric acid.

How many parts in the name of a salt ?—Now there are two parts in the name of every salt, one to show the acid, the other to show the metal. *Sodic nitrate* is a good example ; the last part, *nitrate*, shows that this salt has been made from nitric acid. The first part, *sodic*, shows that it has been done by the metal sodium.

What is potassic chlorate ?—Potassic chlorate is a salt, because its name ends in *ate.* It has been made from chloric acid by the action of the metal *potassium ;* the two parts of its name show this.

See then how the name of a salt shows us its composition. Let us next learn how the names of the bases do the same thing for them.

What two facts about bases will we notice first ? —Every base is called a *hydrate.* Every base contains a *metal.*

Then what two parts in the name of a base ?— These two facts must be shown in the name. To do this, the first part of the name is the name of the metal a little changed, while the last part is hydrate always.

Give examples.—Thus *potassic hydrate* is a base con-

taining *potassium*. Sodic hydrate is a base containing sodium. Calcic hydrate is a base containing calcium.

What elements are indicated by the term hydrate?—The term *hydrate* indicates the presence of hydrogen and oxygen; these elements are always present in bases. Hydrogen, oxygen and a metal of some kind are the elements of a base, and these are always suggested by its name.

What are the constituents of magnesic hydrate?—The first part of this name is to give us the name of the metal; *magnesic*, suggests *magnesium*. The second part, hydrate, means hydrogen and oxygen. So the elements in magnesic hydrate are magnesium, hydrogen and oxygen.

See then how we can tell the composition of a base the moment we hear the name, even if we have never heard of the existence of such a compound before.

Let us now see finally how the names of neutral bodies show their composition. Some salts are neutral, and we have already seen how their names are made. The neutral bodies to be studied now are *binary* compounds.

What is a binary compound?—The word binary means two, so a binary compound is one which is made up of two elements. Water is a good example; it is a binary compound because it contains only two elements, and it is neutral because it has the properties of neither an acid nor a base.

What must the names of such compounds show?—Now the name of any such compound must suggest the names of its elements. Notice this one, *sodic oxide*. Do you see that the first part, sodic, suggests the name of sodium, and that the second part, oxide, suggests the name of oxygen? Sodium and oxygen are the elements in sodic oxide. In the same way *nitric oxide* easily shows that nitrogen and oxygen are the elements combined.

What is carbonic oxide?—Carbon and oxygen are

shown by the name carbonic oxide. These are the elements of that compoud.

But there is another compound made by these two elements; it is *carbonic dioxide.*

What is the difference in composition between carbonic oxide and carbonic dioxide?—Both these names suggest the same elements, carbon and oxygen. Now notice: when the word oxide is used it means *one* combining weight of oxygen. There are *two* combining weights of oxygen in carbonic dioxide, and to show this, the word oxide has the prefix *di*, which always means *two.*

What is mercuric chloride?—From this name we can easily see that the substance is a compound of mercury and chlorine, and because there is no prefix, we are to understand that it contains *one* combining weight of each of these elements.

What is mercuric dichloride?—From this name we also know that mercury and chlorine are the elements in the compound; but because the prefix *di* is used, we know that the compound contains *two* combining weights of chlorine.

What does the prefix tri show?—*Tri* means *three;* used in chemical names it means three combining weights. Thus *gold trichloride* is a compound of gold and chlorine, and contains three combining weights of chlorine to one of gold.

Other prefixes are used, but we will not notice them now.

But there are cases which may possibly puzzle you a little, even when you have learned all that has just been said. Let us see.

What would you call the compound of iron and sulphur?—From what we have heard, it would seem that the compound of iron and sulphur ought to be called *iron sulphide,* but the chemist calls it *ferric sulphide* instead. Why? Simply because *ferrum* is the Latin name of iron, and he chooses to use the Latin instead of the English name.

What other illustration?—The Latin name of copper is *cuprum*, and so the compounds of copper and oxygen are called *cupric oxide*, and *cuprous oxide*.

But we will not add to the illustrations of this method of naming compounds. You have seen how the names of acids, of bases, of salts, and of neutral binary compounds are made to show what elements these compounds are made of. There are many other classes of compounds, and each class contains a very large number of substances; but the chemical name of each one is such as to suggest the composition of the substance itself.

If you *carefully study* the hints just given, you will be able to understand the most common chemical names. This is all that can be undertaken now. Indeed the whole of *this little book is but a hint* as to what the science of chemistry teaches. The science of chemistry is a very wonderful science. It aims to tell us the character of every element, the nature and composition of every compound, and every mixture in the whole world. It searches the molecules of matter and finds their atoms; it embraces the whole earth with its principles, and it reaches out into the heavens and unfolds a a knowledge of what the sun and stars are composed of. Will not some who have read this little book feel a desire to know more of the science whose name it bears?—